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Progress Report

ERIM PROGRESS REPORT ON USE OF ERTS-1 DATA

Summary Report on Ten Tasks

Type II Progress Report
1 July through 31 December 1973

F. J. THOMSON, et al.
Infrared and Optics Division

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ENVIRONMENTAL RESEARCH INSTITUTE OF MICHIGAN
FORMERLY WILLOW RUN LABORATORIES,
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16. Abstract

This third Type II Progress Report under NAS5-21783 describes the ERIM program in utilization of ERTS data as being conducted under a set of ten tasks. These tasks comprise:

I	Water Depth Measurement
II	Yellowstone Park Data
III	Atmospheric Effects (Colorado)
IV	Surveillance of Shoreline Flooding
V	Recreational Land Use
VI	IFYGL (Lake Ontario)
VII	Image Enhancement
VIII	Water Quality Monitoring
IX	Oil Pollution Detection
X	Mapping Iron Compounds

Work to date is reported and research and application plans are presented.

17. Key Words	18. Distribution Statement
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SIGNIFICANT RESULTS REPORTED

Several of the tasks have produced significant results in extracting information from ERTS data. These are summarized as follows.

Task I

Depth mapping's for a portion of Lake Michigan at Green Bay entrance and at the Little Bahama Bank test site have been completed. The results have been verified by use of navigation charts and some on-site visits. These results provide a successful demonstration of the Task I techniques using ERTS data for updating navigation charts.

Task II

Final report is in preparation. A thirteen category recognition map of a portion of Yellowstone Park has been prepared.

Task III

Model calculations of atmospheric effects for altitudes of 7K, 9K, 11K and 13K feet have been prepared. Results indicate that there is little difference in incident spectral irradiance because of a compensating decrease in diffuse irradiance. Water reservoirs in the test site area have been used for empirical investigation of radiance variation with base elevation.

Recognition mapping using ERTS frame 1028-17135 (20 August 1972) to map sixteen terrain classes is under way for part of the test site area.

Task IV

Radar, SLAR, and ERTS-1 data for flooded areas of Monroe County, Michigan are on hand for study. Plans are being made to attempt again obtaining radar and ERTS imagery of lake ice in Whitefish Bay, Lake Superior, Michigan.

Task V

In the land use studies of this task, it has been found that water bodies can be reliably recognized and mapped using maximum likelihood (ML) processing of ERTS digital data. Ponds and/or lakes as small as a hectare in size are usually recognized. Recognition of residential areas depends on the vegetative cover among the residences and streets, which is often a function of the time period since initial development of the residential area.

Wetland mapping has been accomplished by slicing of single band and/or ratio processing of two bands for a single observation date. This approach is cheaper and faster than the ML digital method. Multidate

ML processing also has been used to obtain improved recognition. With the latter approach, wetland types can be differentiated on the basis of standing water and reflectance of vegetation species.

Task VI

Both analog and digital processing have been used to map the Lake Ontario basin using ERTS data. Five recognition maps are presented in this report. One of the figures (Figure 6) compares ERTS-1 and ERIM C-47 borne M-7 scanner results for mapping part of the Niagara River plume as it enters Lake Ontario. The easterly part of the Lake Ontario basin remains to be processed in order to complete the mapping of the entire Lake Ontario Basin utilizing ERTS-1 data.

Task VII

Operating characteristic curves were developed for the proportion estimation algorithm to determine its performance in the measurement of surface water area.

Preprocessing techniques for signature extension were shown to improve machine classification performance in training on one day's data and classifying another day's data over the same scene.

Task VIII

The signal in band MSS-5 was related to sediment (total non-filterable residue) content of waters by a modelling approach and by relating surface measurements of water to processed ERTS data.

A minimum detectable concentration difference of 5 mg/ℓ was deduced from analysis of MSS-5 data from the New York Bight area.

Task IX

Radiance anomalies in ERTS data could be associated with the presence of oil on water in San Francisco Bay (Oakland area) but the anomalies were of the same order as those caused by variations in water sediment concentration and tidal flushing.

INTRODUCTION

This Type II report constitutes the third six month summary of work performed under Contract Number NAS5-21783 by the Environmental Research Institute of Michigan (ERIM). The time period covered is from 1 July 1973 to 31 December 1973.

Ten separate and specific tasks are being pursued under the above contract. The progress to be reported for each task varies because some investigators have only just received data. Some tasks are near the final report writing phase of their investigation. In addition, the direction taken by the various tasks is not precisely the same because task objectives differ. For these reasons, the following report includes a summary of the previous six month progress as well as results and conclusions on a task by task basis.

Objective

The overall objectives of the ERIM ERTS program is to demonstrate the feasibility of solving natural resources and environmental quality problems using ERTS collected multispectral data. Specifically, the individual task objectives are:

Task I	Detection, location and measurement of the depth of shoal areas,
Task II	Computer mapping of terrain features in the Yellowstone National Park,
Task III	Investigation of atmospheric effects on the accuracy of mapping rock types and land use categories, in Cripple Creek-Canon City, Colorado, area,
Task IV	Surveillance of shoreline flooding and erosion in the Great Lakes with simultaneous MSS and radar imagery.
Task V	Mapping of land uses and physical characteristics in SE Michigan to identify areas for recreational uses and open space preservation,
Task VI	Delineate air-water-land interactions in the Lake Ontario Basin as a contribution to the IFYGL,
Task VII	Development of image enhancement and advanced information extraction techniques for ERTS MSS data,
Task VIII	Detection of water pollution and monitoring of water quality for four ocean areas and two lake areas,
Task IX	Detection and monitoring of oil pollution in coastal areas from ships and barges, industrial discharges and major incidents (tanker break-up and oil well leaks), and,
Task X	Detection and mapping of iron compounds and related geologic features in Wyoming (Atlantic City District at SE end of Wind River Range).

Scope

ERTS produced imagery and MSS data (digital tapes) are being studied using human interpretation and computer processing. The resulting mapping and analyses will permit the assessment of satellite produced information in contributing to these specific natural resource and environmental problems. Whereever possible, we are using software previously developed for the analysis of multispectral data collected by aircraft scanners. Formatting programs have been developed to facilitate use of ERTS-CCT's at ERIM.

All tapes are registered in a data management system for reference and to facilitate return of data to NASA when the contract ends. During this reporting period we have augmented our tape storage facilities and continued our survey of all ERTS imagery in house. In two cases of tape shipment errors, we have cooperated by sending the tapes on directly to the intended Principal Investigator rather than first returning them to NASA-GSFC. In one case, we also found where the tapes for Task VI had been missent and accomplished a trade in minimal time.

Entry of all ERTS imagery into our DMS (Data Management System) is still in process.

All simulated ERTS-1 tapes that were on hand have been shipped back to NASA-GSFC in accordance with instructions for return of tapes. In the next two month bi-monthly period, we expect to complete our survey of tapes on hand and send back to NASA-GSFC a large number of tapes that are no longer needed for completion of the ten tasks of the ERIM program.

Third Type II Progress Report
F. C. Polcyn, MMC 063
Task I, Water Depth Measurement

PROGRESS

During this period, verification of depth mapping in Lake Michigan was completed using data with a lower sun elevation angle than was used for the Little Bahama Bank Test Site. This test covered the area near the entrance to Green Bay. Islands submerged due to high lake levels were mapped to a depth of 2 meters using bands 4 and 5 of ERTS. This represented updated information not present on available navigation charts.

A visit to the Bahama test site during this period also established the interpretation in the detectibility of sand shoals and the differentiation with turbidity plumes of a few miles in extent associated with schools of fish in the area. By using a time sequence of ERTS Frames the patterns due to fish even separated from the sand shoals created by shifting currents.

A report of these results was presented at the third ERTS Symposium in Washington on 10-14 December 1973.

PLANS

Plans for the next period are to write and complete the final report which will incorporate both technical results and potential benefits of this new depth mapping capability.

NEW TECHNOLOGY

The use of multispectral sensors and subsequent calculations with two or more channels has been shown to give water depth measurements in those areas where a bottom reflection is obtained.

This new technology provides a capability to update world navigation charts to and thereby improve ship safety.

RECOMMENDATIONS

Since this technique has been successfully demonstrated operational demonstrations in selected uncharted areas should be initiated.

Third Type II Progress Report
Frederick J. Thomson, MMC 077
Task II, Yellowstone Park Data

This task is in the final report writing stage. The report should be completed during February 1974.

Integration of materials for the final report is under way, which includes the thirteen category recognition map, sections prepared by Dr. Harry Smedes, U.S.G.S., and the ERIM summary of the project results on recognition and mapping of land use areas for the area of the Yellowstone Park used as a test area.

Third Type II Progress Report
F. Thomson, MMC 137
Task III, Atmospheric Effects

INTRODUCTION

The automatic classification of terrain objects by pattern recognition devices for this task is based exclusively on the spectral radiance of those objects as collected by the ERTS MSS. In this task, we intend to examine several factors which are likely to influence the resultant spectral radiance of terrain objects that exist in regions of widely varying base elevation. Of primary interest is the effect of varying atmospheric thickness between sensor and target caused by topographic changes. Additional factors to be studied include changes in slope and aspect of the target, seasonal variations of the target, and to some extent, the horizontal nonuniformity of the atmosphere.

The test site for this task consists of a mountainous region in central Colorado covering Cripple Creek, Canon City, and Pikes Peak. The general objectives of this task are to determine the effects of the atmosphere on the ability of pattern recognition devices to classify terrain objects and to assess their significance relative to other factors affecting the automatic classification of terrain objects. The project is a cooperative one between ERIM personnel, Dr. Harry Smedes of the U.S.G.S., and Mr. Roland Hulstrom of Martin-Marietta Corporation.

PROGRESS

During the previous reporting period, a Data Analysis Plan was formalized and submitted for approval. In that Plan, the availability of acceptable ERTS data and atmospheric measurements were summarized and a procedure set forth for accomplishing the work statement for this task.

Technical progress to date can be divided into two separate phases of activity: the evaluation of atmospheric effects and recognition mapping of the test site.

Evaluating Atmospheric Effects

Data of 20 August 1972 (Frame 1028-17135)

In an effort to arrive at some idea of the magnitude of radiance variations to be expected in ERTS data as a result of changes in base elevation, preliminary theoretical calculations and empirical observations were made using visibility conditions reported by a weather reporting station at Colorado Springs, and ERTS data, respectively, for the date of 20 August 1972.

Theoretical calculations were made with a radiative transfer model developed by Dr. R. E. Turner of ERIM. A horizontal visibility of 160 km. reported by Colorado Springs at the time of ERTS overpass on 20 August 1972 was used to specify atmospheric state. Since no measured optical depth parameters were available for this date, the use of horizontal visual range enables identifying the total optical depth by referencing a standard atmospheric aerosol profile (Elterman) for use in the calculations. To simulate changes in optical depth caused by variations in atmospheric path length (as a result of varying base elevation), the standard atmospheric Rayleigh term of optical depth was adjusted for base elevation increases by multiplying the Rayleigh optical depth by the ratio of the barometric pressure at altitude to the barometric pressure at sea level. The aerosol term of the optical depth was unchanged.

Model calculations were made for base elevations of 7K, 9K, 11K, and 13K ft. These base elevations span the range of elevations found in the test site. Results indicated little difference in the total amount of spectral irradiance incident on an object at 7K ft. and one at 13K ft. Although atmospheric transmittance increased with decreasing path length (increasing base elevation) for each of the four MSS bandwidths, the percentage of diffuse irradiance decreased by a similar amount. As one would expect, the changes were greatest for MSS 4. For this bandwidth, transmittance increased by 1.5% from 7K to 13K ft. while the percentage of diffuse irradiance relative to the total was seen to decrease by 1.6% for the same base elevation increase. Thus, for the atmospheric state hypothesized on the basis of reported visibility conditions, computed variations in spectral irradiance for the range of base elevations existing in the test site seem to be slight since increases in direct illumination (as affected by transmittance) are similarly offset by decreases in diffuse illumination. In like manner, computed total and path radiance for objects of low reflectance had negligable variations for assumed background contrast ratios at different base elevations.

Empirical observations of radiance variations as a function of base elevation were made with ERTS data collected on the same date. Water reservoirs were selected because of their common orientation to the ERTS sensor. Converted spectral radiances for each of nine reservoirs were plotted as a function of base elevation. (See Seventh Type I Report for period of 1 September - 31 October 1973). A lack of obvious correlation suggested that the natural variability of water reflectance exerted more influence over observed radiance than did variations in atmospheric path radiance and transmission caused by changes in base elevation.

Data of 16 February 1973 (Frame 1208-17145)

Inspection of ERTS data from a 16 February 1973 overpass (a snow-covered scene) has indicated that the radiance of snow exceeds the dynamic range of the MSS for bands 4 and 5 -- the result being maximum integer levels recorded for all resolution elements over snow. The result is supported by Hulstrom's field measurements of 16 February, but could not have been predicted in advance. Signals in band MSS-6 appear to be clipped for some of the six detectors and not for others -- a result at variance with Hulstrom's field measurements, which indicate that snow signals probably should be clipped. In band MSS-7, snow signals are not clipped, and we have Hulstrom measurements of snow radiance. This may permit a calibration of band MSS-7. Since the atmospheric effects are negligible because of the good visibility and high elevation, Hulstrom's radiance values should agree closely with the radiance from the scanner. Turner's model can calculate corrections for atmosphere if a more precise calibration is desired.

Further study with ERTS data of 21 June will compare the use of measured optical depth parameters against horizontal visual range estimated. Comparisons of measured and predicted irradiance levels at the ground will be made.

Recognition Mapping

The data of 20 August 1972 (frame 1028-17135) provides good coverage of the test site and is being used for the initial recognition map. Sixteen categories of terrain classes were preliminarily defined as being significant for classification by Dr. Smedes. Training areas for each category were initially delineated on an eight level digital graymap of band 5 that depicted every second pixel in every second scan line. This effort was provided by Mr. Jon Ranson, an assistant of Dr. Smedes at Colorado State University, with the aid of high altitude color photography and U.S.G.S. topographic map sheets. Evaluation of resulting signatures for each category showed excessive statistical variability and bi-modality in many cases, possibly indicating imprecisely located training areas. Selected portions of the test site were therefore remapped to allow the display of each pixel into one of 17 quantum levels in order to facilitate accurate location of training areas.

Once accurate signatures are established, further statistical analyses will attempt to determine their suitability for accurate classification of the test site. Variations among signature means (within channel and between channels) will be related to the physical characteristics of the training sets, slope and aspect variations, and if possible, to varying base elevation. However, the inherent variability of natural materials and varying slope and aspect may preclude any correlation between signatures of terrain classes and base elevation. The combination of some preliminarily defined categories and definition of additional categories is also to be considered. The final set of signatures will be used to classify the test site according to the maximum likelihood ratio criterion.

PROGRAM FOR NEXT REPORTING INTERVAL

In accordance with contract requirements, a Data Analysis Plan describing future plans for technical work was submitted in November 1973. Pending notification of its approval, further efforts will be concerned with the completion of both phases of activity for this task during the following six month period.

NEW TECHNOLOGY

None

CONCLUSIONS

The following preliminary conclusions are stated as a result of the reported evaluation of atmospheric effects:

1) The empirical study of water signatures shows apparantly random variation of water radiances with elevation. The variations are of such a magnitude as to be explainable by plausible variations in water quality. Further study will put the magnitude of atmospheric effects changes with base elevation in better perspective.

2) The atmospheric model of Dr. Turner calculates ERTS observed water radiance closely with assumed water reflectance and meteorological visibility input. The ratio of path radiance to total water radiance is high, even for the elevations and clear visibilities of this test site. Further work with actual measurements input into Turner's atmospheric model will hopefully establish how useful this procedure is for calculating atmospheric correction factors.

RECOMMENDATIONS

None

Third Type II Progress Report
M. Leonard Bryan, MMC 072
Task IV, Lake Ice Surveillance

INTRODUCTION

As has been pointed out in previous reports, the nature of the winter in the 1972/1973 winter ice season on Lake Superior precluded the collection, via both SLAR and ERTS-1 Sattèlite, of data concerning lake ice. Consequently, the main thrust of the project was in a state of default. At that time when all remote sensing systems were operative, the ice conditions in the study area had deteriorated to a state that precluded the proper conduct of the project. Consequently, areas of Monroe County under floods, were flown.

PROGRESS

Two previous reports have presented brief analyses of the data which has been obtained. Both were presented as a part of the Sixth Bi-monthly (Type I) report. The first covered field data concerning ERTS-1 band spectral signatures of several ice and snow types. The subject of the second was the SLAR data from Monroe County, and had as its major objective a presentation of the data as opposed to the (visual) analysis of this imagery.

Additional progress has been impeded by funding constraints - based partially upon the desire to determine if it would be at all possible to conduct the experiment, as originally conceived, during the 1973/1974 winter season.

PROGRAM FOR NEXT REPORTING PERIOD

It now appears that we shall be able to collect the originally proposed data, but during the 1973/1974 ice season. This will be at no additional cost to NASA because funds for the 1972/1973 work were not exhausted. Consequently, we have requested a no cost extension which will allow the completion of the original task. (See attached letter).

Work on the visual analysis of the flooded areas of Monroe County, Michigan will progress. Imagery, both SLAR and ERTS-1, for these areas of Monroe County is available. However, in an effort to fulfill the original intent of the proposal, we have deferred spending additional sums pending the successful completion of ice imagery flights for Whitefish Bay, Lake Superior Michigan. These flights are scheduled for the February/March 1974 time period.

ERTS-1 data, within the original framework, has all been received. It will be necessary to special order the ERTS-1 imagery for the study area for the February/March 1974 time period, should this 1974 radar flight prove successful.

NEW TECHNOLOGY

None

CONCLUSIONS

1) It appears as if data from both the ice and the Monroe County flooded areas will be visually analyzed within the original and amended plans of this project.

2) Data for the ERTS-1 passes of February/March 1974 will have to be ordered retroactively.

3) A no cost time extension, to 30 September 1974 is requested.

RECOMMENDATIONS

None

ENVIRONMENTAL
RESEARCH INSTITUTE
OF MICHIGAN

FORMERLY WILLOW RUN LABORATORIES, THE UNIVERSITY OF MICHIGAN

P. O. BOX 618 • ANN ARBOR • MICHIGAN • 48107

PHONE (313) 483-0500

TWX: 810-223-7019

7 January 1974

NASA
Goddard Space Flight Center
Greenbelt, Maryland 20771

Attention: Mr. Douglas Frye/Code 245

Subject: NAS5-21783

Dear Sir:

Warm weather, as well as delays in funding, last year precluded our performance of the original objectives of Task IV of subject contract. Ice flights are now planned for the same study area in March of 1974 as well as the combination of SLAR flights as closely as possible with the ERTS (1) passes. It is therefore requested that a no-cost time extension to 30 September 1974 be granted for Task IV of subject contract.

Sincerely,

J. R. Welch

Joseph R. Welch
Contract Administrator

JRW:jw

cc: E. Szajna-NASA Goddard

193305

Third Type II Progress Report
I. J. Sattinger, MMC 086
Task V, Recreational Land and Open Space

INTRODUCTION

Major effort during this reporting period was devoted to analyzing the results of likelihood ratio processing of a 150 sq. km. area in Oakland County. This is the same area previously mapped by edited level slicing techniques and the same ERTS digital data (acquired on 28 September 1972) was used in the likelihood ratio mapping. A study also is being made of the usefulness of ERTS data for wetland mapping using both spectral and phenological variations in cover type reflectance. This study is based on analysis of signatures of wetland areas taken from two ERTS frames acquired on 27 March 1973 and 7 June 1973.

PROGRESS

Maximum Likelihood Ratio Processing

The training areas on which to base maximum likelihood ratio processing included residential areas, sand and gravel pits, forest areas, other vegetative cover, and deep and shallow water (see Table 1). Since the coverage was obtained near the end of the growing season, very little bare soil is visible in the area. In selecting these training sets, we experienced several difficulties which somewhat limited the accuracy of our recognition mapping process. In some cases, training areas were inadvertently chosen which were later found to be covered by haze or clouds.

We also encountered difficulty in selecting an area on the initial computer printout which coincided with a known area recognized on an RB57 photograph. As a result, the surface covered by the training set was not a homogeneous type of ground cover in some cases. In spite of these initial problems in selecting suitable training sets, maximum likelihood ratio processing produced effective results.

In future processing, we will be able to improve our results by working with a cloud-free frame acquired on 7 June 1973, so that contamination of the signatures by cloud cover will not occur. We will also adopt improved methods of selecting homogeneous training areas based on accurate geographic correlation of gray map and photograph.

The signature of water bodies is sufficiently different from other types of surface that they are reliably recognized and mapped. Large bodies of water such as lakes, are mapped with very little error. Even bodies of water as small as a hectare in size are usually detected, although their shape is disorted by the grid structure of the map, and their apparent area is subject to considerable error.

TABLE 1
TRAINING SETS

OAKLAND COUNTY, MICHIGAN, TEST SITE

Training Set	Number of Pixels	Hectares
Water, shallow or haze-covered	1121	500
Water, deep	2318	1020
Soil; gravel	1899	839
Medium density residential	3924	1730
Medium density residential (haze)	2714	1200
Medium density residential (haze)	1780	785
Medium density residential (50% vegetation)	1512	668
Trailer park	435	192
Mixed hardwood forest	7821	3450
Transition (forest/grass)	3858	1700
Grass; upland brush	6478	2860
Grass; active cultivation	5902	2605
Golf course	1835	810
Unclassified	35	15
TOTAL	41632	18374

TABLE 2
ACCURACY COMPARISON

OAKLAND COUNTY, MICHIGAN, TEST AREA
FOR FOUR LAND COVER CLASSES USING A TEST TRANSECT

	Pixels in Class Correctly Identified	
Class	ERTS Photointerpretation (percent)	ERTS Digital Mapping (Percent)
Water	89	89
Urban	44	74
Vegetation	92	97
Forest	52	92
Overall	74	92

Residential areas with little vegetative cover tend to be mapped as homogeneous areas similar to sand or bare soil. This situation would be approached for a trailer park. In areas containing substantial amounts of trees and lawn, the mapping consists of a mixture of light tones and various types of vegetation. Thus, residential areas with substantial vegetative cover have to be recognized not from single pixels but from textural analysis of a group of such pixels. The heterogeneous character of residential areas may provide a basis for distinguishing such areas from trailer parks, bare fields, sand and gravel pits, commercial and industrial areas, and for delineating rural/urban boundaries.

In the test area, the trees are predominantly deciduous, with the majority of the forest-covered areas consisting of mixed upland and lowland hardwoods. Two separate training sets were used to identify forests. The resulting training sets were consistently recognized as forest in the recognition map, confirming the estimate that these training sets were selected in areas of homogeneous forest cover. Visual comparison of the recognition map with aerial photography indicates a reasonably good correlation of location, size, and shape of wooded areas as small as 5 or 10 hectares. There may, however, be a tendency to map as forest some areas which have been designated in the vegetation map of Oakland County as upland brush. No attempt was made in this recognition mapping process to distinguish among various communities or species of trees. For many studies of recreational land, such differentiation of tree types would be significant. This problem is being addressed under another subtask of this investigation.

A check on the accuracy of recognition mapping of vegetation categories other than forest is difficult to accomplish in the area under study. The rural areas are characterized by great variability of surface cover and there are few homogeneous areas of sufficient size to be isolated for comparison with aerial photography. In the current results, the general mapping of other vegetation as a single group appears to be quite effective, but the distinction among individual categories is inconclusive at this time.

One suitable approach to the task of checking the computer map accuracy is to compare the shape and extent of sizable features on the map and photograph. General conclusions reached from this method of comparison have been discussed above. In addition, an accuracy check was performed on an East-West transect taken through the northern part of White Lake and a large trailer park several miles east which was used as the training set for one of the urban classes. This transect contains 227 pixels. The accuracy of the digital map prepared by maximum likelihood ratio processing was checked by comparing it to an RB57 color IR photograph of the area. A similar accuracy check was performed on a land use map obtained by conventional photointerpretation of the ERTS image of the same area.

Table 2 shows the comparison of pixel classification from the two sources. The matching data were aggregated into the four major classes of water, urban, forest, and other vegetation. The number of matching pixels amounted to 208 out of 227, for an accuracy of 92%. These results may be compared with the match of RB57 photography against the same transect of a land use map prepared by photointerpretation of ERTS imagery. For the same four classes, the number of matching pixels yielded a total of 169 out of 227 for an accuracy of 74%. In comparing this latter result with the accuracy cited for digital mapping, it should be kept in mind that this result was probably not the best possible performance that can be expected from ERTS photointerpretation. However, a significant advantage of digital mapping over ERTS photointerpretation probably accounts for some of the difference. Every pixel in the complete scene is analyzed by the digital processing, whereas with photointerpretation, realistic limitations on photointerpretation effort require the placing of boundaries around what appear to be homogeneous areas of land cover.

Analysis of Wetland Mapping

The computer processing of Oakland County ERTS data did not concentrate on the problem of distinguishing between different forest species or mapping specific types of wetlands. Since consideration of the characteristics of these cover types is often of great importance in recreational land-use planning, a supplemental study is being conducted over nearby Michigan areas to evaluate the use of ERTS-MSS data for this purpose.

We chose to conduct this study through a combined program of ERTS-multispectral scanner (MSS) signature analysis and computer recognition mapping of several natural areas maintained by the University of Michigan (U of M) and the Michigan Department of Natural Resources (DNR).

The U of M sites include the E. S. George Reserve (used for habitat response/white-tailed deer population management interaction research), and Stinchfield Woods (the School of Natural Resources experimental forest). The state land examined comprises the Chelsea-Waterloo and Pinckney Recreation Areas. These sites include a variety of homogeneous stands of individual forest species common to the Great Lake States, as well as wetlands large enough to serve as useful training areas for MSS signature extraction and analysis. Additional impetus for choosing these sites is derived from our staff's familiarity with the training areas and the comprehensive documentation of the types and distribution of surface cover which exist for these areas.

Up to this point, the study has been conducted using ERTS data collected over the test areas on the following days: 27 March 1973 (frame 1247-15481) and 7 June 1973 (1319-15474). The signature analysis indicates that reliable discrimination of major structural associations of vegetation (e.g., forest, grasslands and brush) and percent vegetation cover in grasslands can be obtained through use of level slicing of single band data and/or ratio processing of two bands for a single date. These processing methods are more rapid and economical than maximum likelihood ratio processing.

On the other hand, signature analysis also indicates that when using the maximum likelihood ratio method to process data of different seasons, the multidate or temporal recognition of individual wetland types is improved over recognition processing of either single date alone. In this case the seasons analyzed are spring and early summer. Using this form of processing, recognition of various types of wetlands is now based on observation of both standing water and the reflectance of vegetation species. Water is easily differentiated from other types of surfaces, so the amount and distribution of open water surface in a scene is easily observed. Thus, areas which are covered with water during the spring but dry or covered with vegetation during the growing season are easily separable from those areas either permanently water covered or dry throughout the year.

Certain types of wetlands which are at least partly vegetated in the spring and fully covered later in the growing season can be differentiated by analyzing the reflectance changes that characterize this phenological development of the vegetation. Using these spectral features of phenological discrimination, combined with the open water recognition, it was possible to detect differences in the MSS signatures of the following cover types:

Wetlands	Uplands
Deep lakes	Hardwood forests
Shallow lakes	Pines
Deep marshes	50 - 75% Hardwood tree cover/grass
Shallow marshes	Grasslands
Shrub swamps	Bare soil
Lowland hardwood forest	
Bogs	
Wet meadows	

Further analysis and tests will be required to confirm these preliminary estimates of the capability of ERTS for wetland and upland recreational site mapping in Michigan. This requires the merging of the data from the two ERTS frames. This has been accomplished through digital registration of the same area on the two frames mentioned earlier, using an algorithm which matches a set of identical points on each frame. It is now possible to generate composite recognition maps produced by joint processing of each frame individually, or by selecting data from the spectral channels of both dates for individual pixels.

Some confusion of group recognition will still be encountered even under optimum conditions, since the natural variations in seasonal water cover and vegetation, even for a single wetland type, will cause difficulty. Nevertheless, it appears that ERTS can provide a capability for total enumeration of wetlands mapping of large regions in the Lake States with accuracy that would be difficult to duplicate by other means.

A practical method of mapping wetlands over large areas would be to use a multi-stage sampling method. A recognition map can be prepared from computer processing of ERTS data by separately processing individual elements of the scene covering about 0.5 hectare; in actual practice, the recognition capability will be limited to homogeneous areas of individual wetland types which are at least one or two hectares in extent. This limitation is due to the problems of recognizing elements which contain mixtures of components and problems of precisely superimposing data from two or more ERTS frames. The resulting map produced from ERTS imagery can then be augmented by using aerial photography to select sample areas for more detailed analyses. Use of the information collected for these sample areas will permit further interpretation of the ERTS results and, perhaps, more detailed estimates of wetland conditions.

PROGRAM FOR NEXT REPORTING PERIOD

Project effort during the next reporting period will be concentrated on two tasks. Analysis of signature data from ERTS frames acquired on 27 March 1973 and 7 June 1973 will continue for the areas presently being studied, in which good ground truth is available on tree species or communities and on wetland areas. A digital map will be completed showing the recognition of the water bodies and major vegetation types present. The second task will be to repeat the processing of the same test area in Oakland County previously analyzed using cloud-free data from the 7 June 1973 frame and improving the selection of homogeneous training areas.

NEW TECHNOLOGY

None

CONCLUSIONS AND RECOMMENDATIONS

Using maximum likelihood ratio processing, water bodies can be reliably recognized and mapped. Even bodies of water as small as a hectare in size are usually detected. Residential areas with little vegetative cover tend to be mapped as homogeneous areas similar to sand or bare soil. Residential areas with substantial vegetative cover have to be recognized not from single pixels but from textural analysis of sizable areas. Although residential areas are generally distinguishable from other types of land use, some confusion might occur for residential areas whose composition closely approximates either completely paved areas or completely vegetated areas. Wooded areas as a group can be distinguished from other types of vegetation, but additional work is needed to develop methods of distinguishing among various communities or species of trees. More work also needs to be done on distinguishing among other types of vegetation. An accuracy check along a test transect indicates that four categories listed above can be distinguished from each other with an accuracy of 92% (see Table 2).

Studies of wetland mapping performed to date indicate that reliable discrimination of major structural associations of vegetation and percent vegetation cover in grasslands can be obtained through use of level slicing of single band data and/or ratio processing of two bands for a single date. These processing methods are more rapid and economical than maximum likelihood ratio processing. Signature analysis also indicates that when using the maximum likelihood ratio method to process data of different seasons, such as spring and early summer, the multidate or temporal recognition of individual wetland types is improved over recognition processing of either single date alone. Using this form of processing, recognition of various types of wetlands can be based on observation of both standing water and the reflectance of vegetation species. It is thus possible to discriminate a number of types of marshes, swamps, forests, grasslands, and water bodies.

Third Type II Progress Report
F. C. Polcyn, MMC 114
Task VI, IFYGL (Lake Ontario)

INTRODUCTION

ERTS-1 coverage of the 32,000 square mile Lake Ontario Basin is being used to study temporal and spatial changes which affect many aspects of the hydrology of the Great Lakes. As part of the International Field Year for the Great Lakes (IFYGL) -- a coordinated, synoptic study of the Lake Ontario Basin -- processed ERTS-1 imagery is contributing to the data base of synchronized observations made by investigators from many U. S. and Canadian government agencies and universities.

The objective of this task is to establish quantitative relationships between ERTS-observed features and significant hydrological parameters. Initial correlations are being done on selected representative basins within the Lake Ontario Basin, with the ultimate aim of extending these relationships, to an analysis of factors which affect the terrestrial water balance over the entire Lake Ontario Basin.

Data analysis is being concentrated on the August 19, 20, 21, 1972 and July 8, 1973 ERTS imagery (9 Frames) which represent virtually cloud-free coverage of the entire basin. Imagery from subsequent ERTS passes is being manually analyzed.

PROGRESS

Work performed during the period 1 July to 31 December 1973 included 1) analog computer processing of ERTS data for most of the Lake Ontario Basin and 2) digital computer signature analysis and processing of the East and Middle Oakville Representative Basin. During this period meetings were held with co-investigators in Toronto and Guelph, and oral presentations concerning the progress of the program were made at NASA-Goddard (26 October), NOAA-CEDDA (27 October) and IFYGL-Terrestrial Water Balance Panel (11, 12 December) in Detroit. There are no major problems to report at this time. The procedure and interim results of the analog computer processing are discussed in a separate report (in preparation) to NASA. It is expected that all of the proposed objectives of this project will be completed within the revised contract period.

ANALOG PROCESSING

During this reporting period data processing was accomplished in accord with the plan outlined in the Second Type II Report. Portions of eight ERTS frames of the Lake Ontario Basin were dark-level adjusted and scaled using the subroutine DRKSCL. These data were then converted to

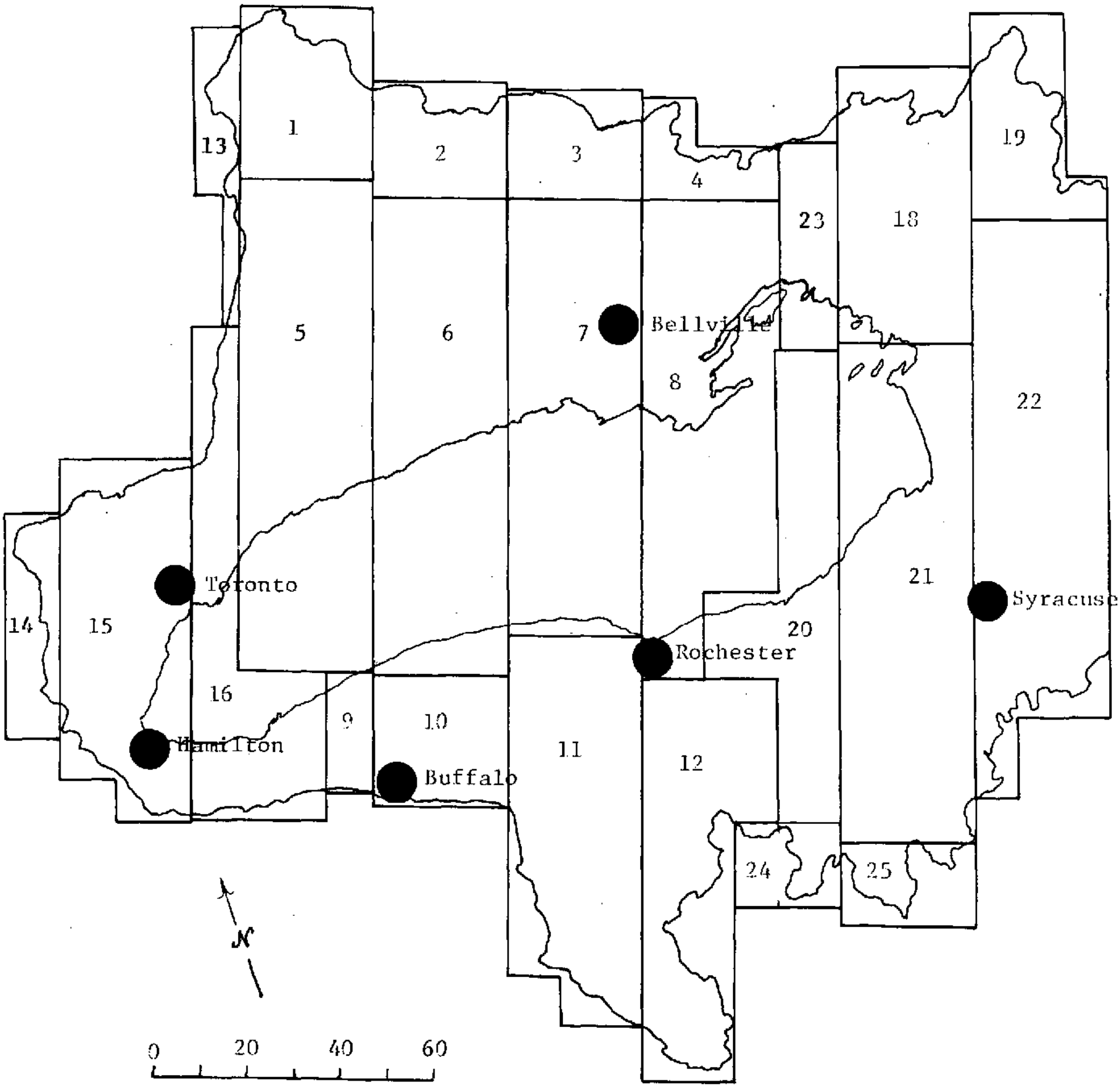

FIGURE 1. Drawing showing tape segments used to represent the maximum extent of the Lake Ontario Basin (eastern portion excluded)

the analog format which is compatible with the ERIM Spectral Analysis and Recognition Computer (SPARC). Three one-inch analog tapes were required. The tapes were then manually gated in such a way that 25 rectangular segments were selected to approximate the maximum extent of the Basin for all but the eastern-most portion of the Basin (Black River watershed). Figure 1 shows an outline mosaic of the segments in relation to the Basin boundary. Tape segments representing the Black River watershed are to be added at a later date. Note that the data were edited so that complete coverage of the Basin area plus some non-Basin adjacent areas were obtained--this due, in part, to the desire to obtain surface-coverage of the entire Basin and the uncertainties attendant with watershed boundary definition. Further discussion of the editing procedure is contained in the Type I report for September 1973.

Analog processing of these data consisted of producing 70 mm negative transparencies for four dark-level adjusted video images of the Basin (one for each ERTS band), a (0.8-1.1 μm) / (0.6-0.7 μm) ratio image, and 10 surface recognition images. The recognition images were produced in two ways; 1) level (density) slicing of selected single-channel videos and 2) computing a likelihood ratio based on inputs of two ratios, (0.9-1.1 μm) / (0.6-0.7 μm) and (0.7-0.8 μm) / (0.6-0.7 μm). The following general recognition classes were produced (1) surface water (includes cloud shadows), (2) clouds, (3) impervious materials, (4) industrial areas (includes clouds), (5) urban commercial and residential (includes bare soil and rock types), (6) dense woody vegetation (deciduous and coniferous), (8) vigorous herbaceous vegetation (includes golf courses), (9) non-vigorous or sparse vegetation (includes ripening field crops), and (10) mixed shrub vegetation associated with idle fields and pastures.

Problems encountered during this data processing included difficulties in accurate spatial editing, some uncertainties concerning training set designations, possible mis-registration of ratioed ERTS data channels, and an inability to exclusively recognize certain urban and non-urban categories. While none of these problems are considered serious enough to jeopardize the objectives of this ERTS program, the advantages associated with high-speed analog processing must be weighed against some of its current disadvantages. These problems will be discussed in future reports as the data analysis proceeds.

During this reporting period, black and white image mosaics were prepared for the above recognition classes (white represents target class, black represents non-target). Three examples are shown in Figures 2, 3, and 4.

Figure 2 shows the distribution of surface water and cloud shadow for the Basin. This image was produced using a level-slice of the 0.8 - 1.1 μm ERTS band. (Considerable detail has been lost in photo-reproduction.) Initial inspections show accurate recognition of surface-water areas of approximately 30 acres in size or greater.

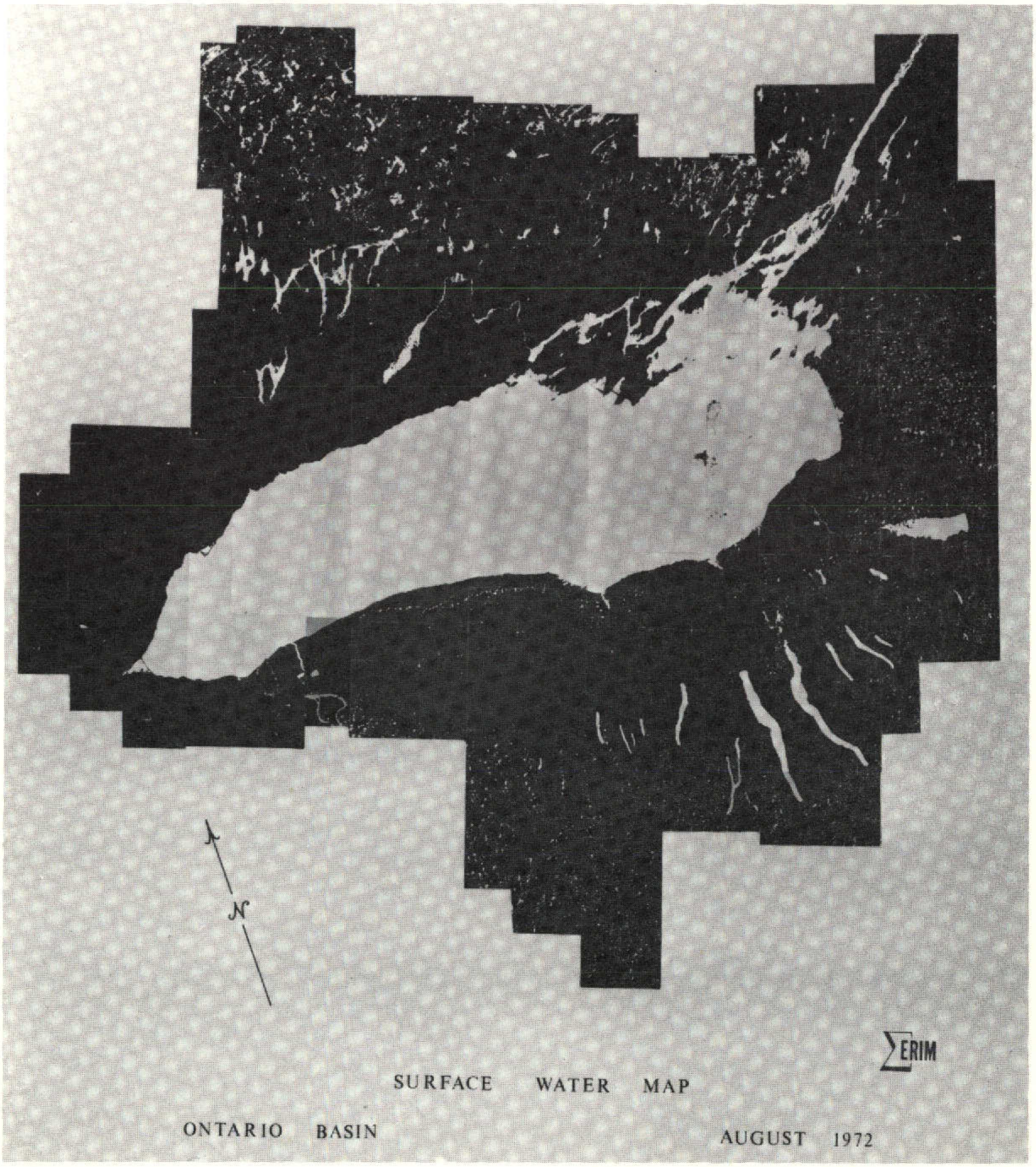

FIGURE 2

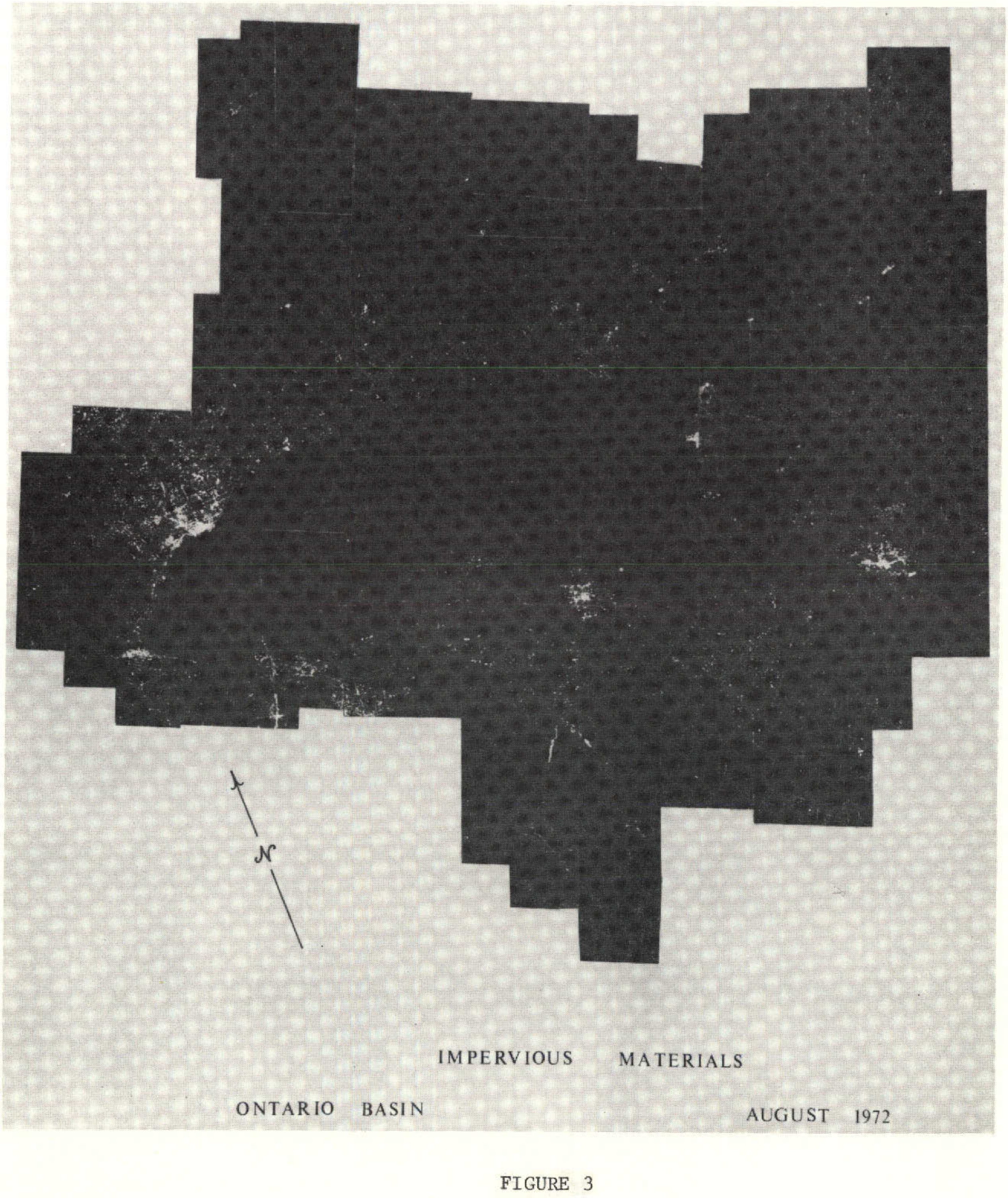

FIGURE 3

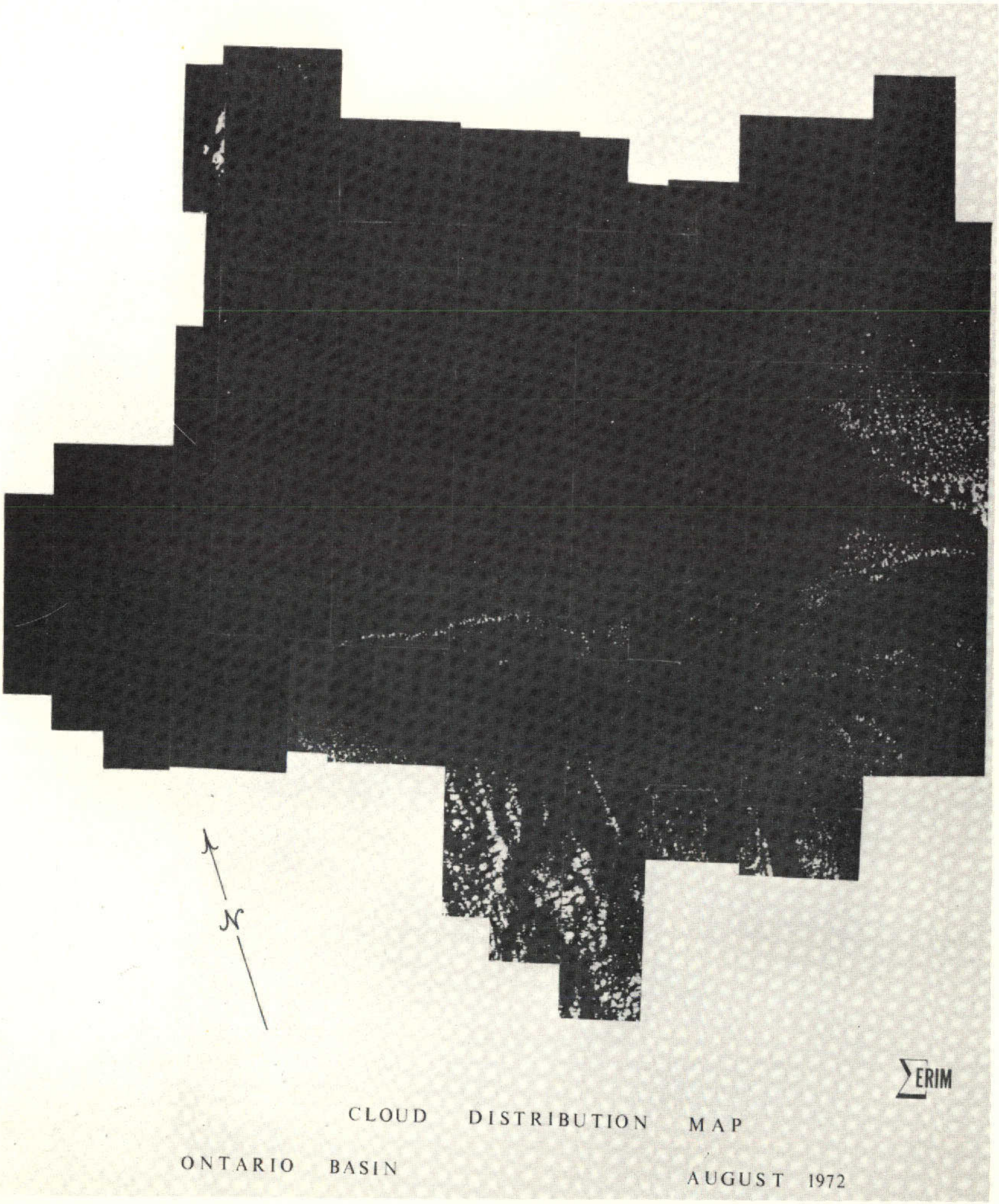

FIGURE 4

Figure 3 shows the distribution of impervious materials--inclusive of heavily developed areas such as large industrial plants, quarries, 8-lane highways, airports and possibly some rock outcrop areas.

Figure 4 shows the recognition of clouds which were present in the scene at the time of ERTS data collection. While not a recognition class of hydrological significance, it is important to recognize clouds for the purpose of evaluating their effect on other recognition categories--i.e., that portion of the Basin is obscured by clouds. For example, it may be noted that the shadows of many of the small cumulus clouds (Figure 4) appear in the surface water recognition image (Figure 2).

DIGITAL PROCESSING

Digital recognition of a portion of the Lake Ontario Basin was undertaken during this contract period in an effort to evaluate the processing procedures and validate the recognition results for the entire Basin. The 80 square mile East and Middle Oakville Creek Representative Basin, located in segment 15 between the cities of Hamilton and Toronto, was selected for this purpose. This Representative Basin is being intensively studied during IFYGL by investigators from the Ontario Ministry of the Environment. Both ERTS data and supporting aircraft data are being processed for this natural watershed located near Oakville, Ontario.

A portion of an ERTS-CCT containing data for this test area was converted to ERIM format and a digital graymap was produced. Signatures were obtained from a number of terrain features thought to be of hydrological significance. Also an editing routine for delimiting the irregular boundaries of natural drainage basins was used to recognize and compile areal statistics dor only the basin area. The program approximates the boundaries of a basin by drawing straight lines between points which occur on the boundary. A total of 64 consecutive points is used with this program, but more exact delineation is possible if one were to divide the basin in to segments--allowing any multiple of 64 points to define any degree of geographical irregularity. Figure 5 shows a digital graymap (0.6 - 0.7 μm) of the East and Middle Oakville Basin. Dark areas show mixed deciduous and coniferous forest vegetation. Light tones correspond to the fourlane highway 401 and bare soil areas. Grey tones of intermediate density show different types and densities of herbaceous vegetation.

PROGRAM FOR NEXT REPORTING PERIOD

Plans for the next reporting period include 1) analog processing of ERTS data obtained from 8 July 1973 to complete recognition for the entire Lake Ontario Basin, 2) study and evaluate the recognition images of the Basin, 3) calculate areal statistics for each of the recognition classes for the Basin and attempt to relate these to parameters of terrestrial hydrology, especially runoff, 4) complete digital recognition processing

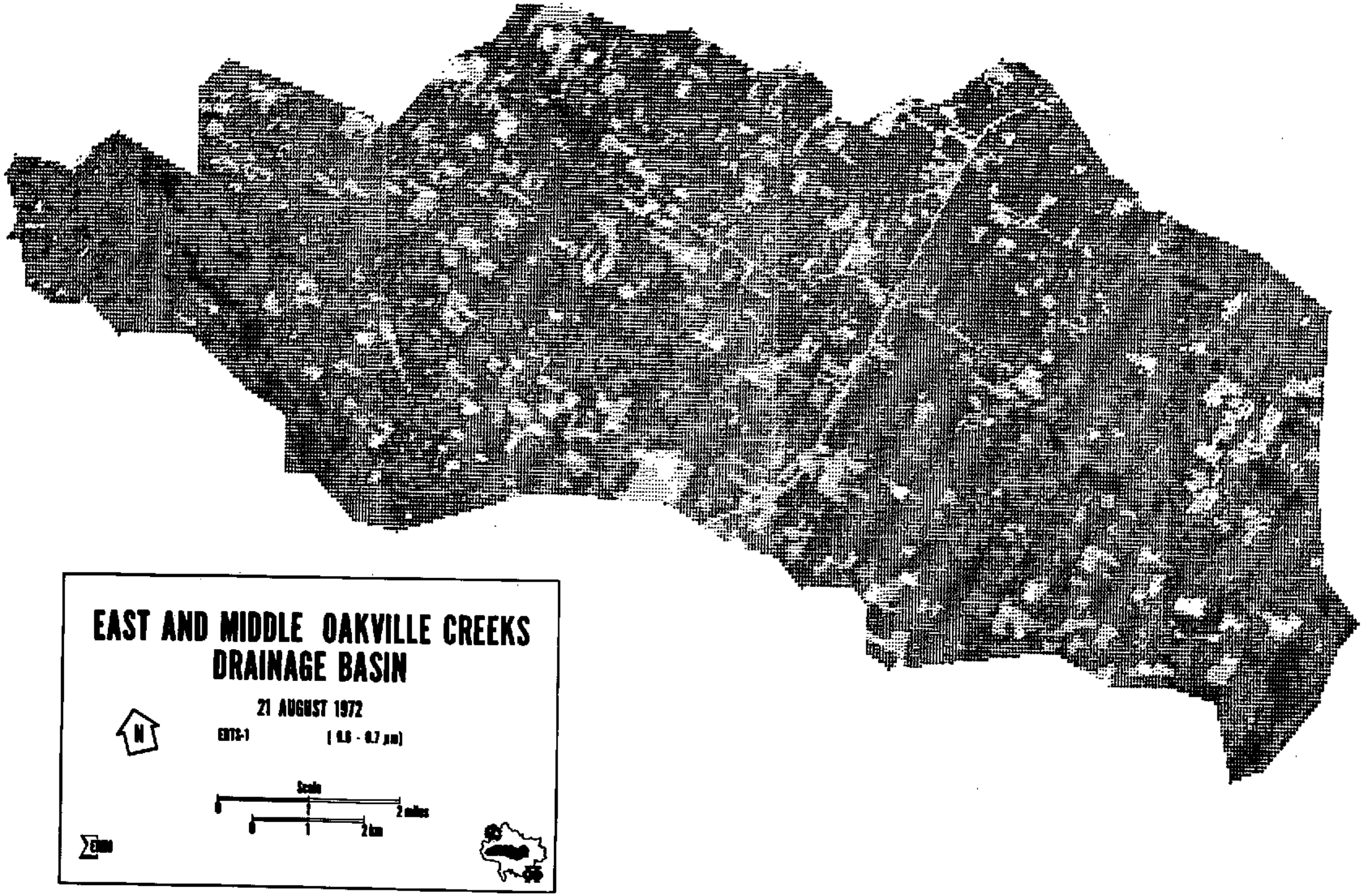
EAST AND MIDDLE OAKVILLE CREEKS
DRAINAGE BASIN
21 AUGUST 1972
N
Scale
0
1
2 miles
0
1
2 km

FIGURE 5

for the East and Middle Oakville Representative Basin, and 5) initiate processing of aircraft and ERTS data for parameters of water quality applicable to data collected on 24 March 1973 (see figure 6). The major portion of the latter part of this reporting period will be applied to documenting all processing, results, and analysis in the form of the final report for this project.

CONCLUSIONS AND RECOMMENDATIONS

No final conclusions or recommendations can be made at this time. Much analysis work needs to be done in order to validate the results thus far produced. In particular, certain trade-offs are apparent in the comparison of digital and analog processing procedures (speed and area coverage versus accuracy and detailed recognition). In turn, these trade-offs must be weighed in terms of the quantity and nature of the information sought for terrestrial hydrology.

ERTS-1 (0.6 - 0.7 μm) ERIM C-47 (.58 - .64 μm)

THE NIAGARA PLUME FROM ERTS-1 AND ERIM AIRCRAFT

24 MARCH 1973

FIGURE 6

Third Type II Progress Report
Period: 1 July through 31 December 1973
W. A. Malila (UN612) & R. F. Nalepka (UN178), MMC 136
Task VII, Image Enhancement and Advanced Information Extraction Techniques

INTRODUCTION

Experience has been gained at ERIM over the past decade in computer processing and extraction of information from airborne multispectral scanner (MSS) data and in modeling atmospheric effects in received radiance signals. The general objective of Task VII is to adapt techniques existing at ERIM for their application to ERTS-1 data, to assess the applicability of these techniques by applying them to selected ERTS-1 data, and to identify any additional problems that might be associated with such processing of satellite multispectral scanner data. Three areas are to be studied: (1) compensation for atmospheric effects in ERTS-1 data, (2) preprocessing for improved recognition performance through signature extension, and (3) estimation of proportions of unresolved objects in individual resolution elements.

The intensive test site for this investigation is an agricultural area South-West of Lansing, Michigan, and the extensive test area also covers several other counties in South Central Michigan. A variety of agricultural crops and woodlots are in the intensive area. The primary crops are corn and wheat, with field beans, soybeans, and alfalfa also represented. The intensive test area is in an overlap region covered by ERTS-1 on two successive days of each 18-day cycle. Skies were clear on 25 August and ERTS data were collected. Simultaneous multi-altitude underflight coverage was obtained by the Michigan C-47 multispectral scanner aircraft, and ground-based measurements were made of spectral irradiance and sky radiance. RB-57 camera coverage of the region, obtained during June, was received in late September. A second RB-57 flight was made in mid-September, and its photography was received at the end of October. A second multispectral scanner aircraft mission was scheduled. Partial coverage was obtained in June 1973 and the site for the remaining lines was moved to the Willow Run Airport and simultaneous coverage was obtained in September 1973.

SIGNIFICANT RESULTS

1. Operating characteristic curves were developed for our algorithm for proportion estimation (i.e., for estimation of the fractional composition of individual pixels) to determine its performance in the measurement of surface water area in our previously reported test site, as a function of a water proportion threshold and a probability of rejection parameter.

2. Preprocessing techniques for signature extension were shown to improve machine classification performance in training on one day's data and classifying another day's data over the same scene. Both an empirical transformation and a theoretical transformation, based on calculated atmospheric effects and ground-based measurements of optical depth, were employed in separate applications of preprocessing.

PROGRESS DURING THE PERIOD, 1 JULY - 31 DECEMBER 1973

Progress was made on all three subtasks of the investigation. The results are summarized in the paper, "Advanced Processing and Information Extraction Techniques Applied to ERTS-1 MSS Data", by the co-principal investigators, which was presented at the Third ERTS Symposium in Washington, D.C., Dec. 10-13, 1973. A copy is included as the Appendix to this report.

PLANS FOR THE PERIOD, 1 JANUARY THROUGH 30 JUNE 1974

We plan to expend the remainder of the investigation resources in pursuing the work that has been started. As part of the effort, we will analyze requested data from the September 6, 1973, pass over our test site, for which there was simultaneous coverage by the ERIM M-7 multispectral scanner.

ADVANCED PROCESSING AND INFORMATION EXTRACTION TECHNIQUES APPLIED TO ERTS-1 MSS DATA

William A. Malila and Richard F. Nalepka
Environmental Research Institute of Michigan, Ann Arbor, Michigan

ABSTRACT

Conventional automatic data processing and information extraction techniques fall short of providing the information required by the user in some applications. For those cases, advanced techniques are needed to permit the extraction of the necessary information. This paper describes advanced techniques we have developed and provides examples of their application to ERTS-1 MSS data.

The techniques described are designed to help overcome problems in location, mensuration, and classification accuracies which result from geometric distortions of the ERTS MSS data, the relatively coarse resolution of the sensor, and variations in atmospheric state over the region to be surveyed. It is shown that each of these factors can seriously degrade one's ability to extract necessary information. Further, it is shown that advanced techniques can alleviate the effects of these factors.

1.0. INTRODUCTION

This paper presents results obtained under ERTS Investigation MMC-136. As a part of this investigation, we have been developing and testing techniques for the extraction of information from ERTS data. The two general objectives of the investigation have been to minimize the effects of large spatial resolution element size and to enhance the extraction of large-area survey data. Two topics under each of these general categories are discussed in the sections that follow.

2.0. TECHNIQUES FOR MINIMIZING THE EFFECTS OF LARGE SPATIAL RESOLUTION ELEMENTS

The first topic in this section is estimation of the fractional composition of individual pixels by use of the spectral information obtained from ERTS. It is followed by a description of a procedure for assigning pixels to specific analysis areas identified on maps or photographs, an important detail for classification processing.

Presented at the Third ERTS Symposium in Washington, D.C., Dec. 10-13, 1973.

2.1. ESTIMATION OF FRACTIONAL COMPOSITION OF INDIVIDUAL PIXELS (PROPORTION ESTIMATION)

One aspect of this investigation is concerned with testing the applicability of advanced information extraction techniques to ERTS-1 MSS data. (These techniques have been developed at ERIM with funding provided by the Supporting Research and Technology program of NASA-JSC under Contract NAS9-9784.) One technique addresses problems associated with accurately determining areas covered by features in the scene using scanners with limited spatial resolution, like ERTS-1 MSS. Clearly, there is a serious problem for features smaller than the instantaneous field of view of the scanner. In addition, problems exist even for larger features since many of the ERTS MSS pixels overlap the boundaries between these and adjoining features. As a result, the radiation represented in those pixels is a mixture of radiation reflected from two or more materials. Since the signals generated in such pixels are not characteristic of any one material, the pixels will generally be improperly classified. Therefore, the area assigned to each material class could seriously be in error. For example, at least 25% of the pixels covering a square field of 50 acres (20 hectares) will overlap its boundaries.

At ERIM we have developed a data processing technique [1] to estimate the proportions of materials contained within each pixel, by taking advantage of the fact that information is gathered in several spectral bands. This permits a more accurate determination of the area covered by each material; the greater the number of spectral bands used, the more the materials that can be considered. We next describe and evaluate the results of a test of this technique on ERTS-1 MSS data. (Some of these results were included in a paper presented at the March 1973 Symposium on Significant Results [2].)

The goal of this initial test was to determine how accurately we could estimate the surface area of a number of lakes and ponds in a small portion of an ERTS frame. The region selected for processing is shown in Figure 1, a black and white aerial photograph of that region.

Using an enlargement of this photo, the surface area of the water bodies was determined. Two methods were used to determine area, dot grid and planimeter, with the results being calibrated by assuming a one mile separation between the section line roads apparent in the photo.

For purposes of comparison, the data were processed using two approaches in addition to the multi-channel proportion estimation algorithm. One of these was the conventional recognition algorithm in which each pixel was assigned to one and only one class. In the other approach, proportions were estimated using only one ERTS-MSS band.

In processing the data the first step was the establishment of training signatures for the major object classes in the scene. The primary scene components in this case were water, trees, and soil. A number of pixels containing pure samples of each of these classes were located and the mean signal vector and associated covariance matrix was determined for each class. Since there were some data quality problems with ERTS Band 6, only Bands 4, 5, and 7 were used to establish signatures and for the ensuing processing.

Having established the signatures, the three processing algorithms (multi-channel proportion estimation, single channel proportion estimation, and conventional recognition) were applied to the data. In order to meaningfully compare the results generated using these algorithms, it was necessary to identify the thresholds which would be used in each of the algorithms. These threshold or parameter values would affect the trade-off between the detection rate and the false alarm rate. For this comparison, it was decided to utilize those parameter values which eliminate water false alarms in the scene (i.e., no non-water pixels classified as water) while at the same time maximizing the detection rate.

The multi-channel proportion estimation algorithm used for estimating water acreage depends upon the values used for two parameters. One of these parameters, ρ, is called the probability of rejection; the other, τ, is the water proportion threshold.

The purpose of the probability of rejection parameter ρ is to eliminate those signals which represent pixels that contain insignificant coverage by a combination of water, bare soil, and vegetation or, equivalently to eliminate signals which represent pixels that contain significant coverage by combinations of other object classes. The probability of rejection parameter ρ operates as follows. If a signal y is not within a probability contour that contains $(1-\rho)$ of the samples for a signature of some mixture of water, bare soil and vegetation, then the proportion of water estimated for the pixel represented by the signal y is taken to be zero.

The objective of the other parameter, the water proportion threshold τ, is to eliminate small proportion estimates of water for pixels which, in reality, contain no water. This parameter operates as follows. A tentative proportion estimate $\hat{p}$ of water is made for the pixel in question. If $\hat{p}$ is less than τ, then the estimated proportion of water is taken to be zero. If $\hat{p}$ is greater than or equal to τ, then $\hat{p}$ is taken as the estimated proportion of water.

Figure 2 gives the operating characteristics of the proportion estimation algorithm for this data set as functions of the probability of rejection and the water proportion threshold. The plots shown in this figure were determined as follows. All the pixels in the scene were classified by photo interpretation into two classes, W and G. A pixel was put in class W if it contained some water; it was put in class G if it contained no water. The total amount of water surface area estimated for the pixels in class G, divided by the area of the pixels in class G, was taken as the false alarm rate. The total amount of water surface area estimated for pixels in class W divided by the actual (as determined by photo-interpretation) surface area of water in class W was taken as the detection rate.

From the figure we see that for $\tau = 0.4$ or greater, the false alarm rate becomes zero, regardless of the probability of rejection ρ. For a specific value of ρ, we may increase the detection rate by decreasing τ, but the penalty is increased false alarm rate. Examination of the operating characteristics indicates that the combination of parameter settings with $\rho = 0$ and $\tau = 0.4$ yields near optimum results: detection rate = 90.24% and false alarm rate = 0. This detection rate is based upon assigning to each pixel an area equal to 79m x 57m.

The single-channel proportion estimation algorithm operates similarly to the multichannel proportion estimation algorithm, with probability of rejection parameter ρ and water proportion threshold parameter τ. In single-channel proportion estimation, the ρ parameter was used to eliminate those signals which represented pixels containing insignificant coverage by a combination of water and vegetation (proportions may be estimated for only two classes when using a single channel). Because the water signal level in ERTS Band 7 was lower than all others in the scene, a value of zero could be used for the parameter ρ without causing false alarms. Therefore, the results given in Figure 3 are for $\rho = 0$ and varying values for the parameter τ. We see that as τ decreases the detection rate increases, with a penalty of increased false alarm rate. A false alarm rate of zero is achieved for τ values of 0.6 or greater.

For conventional recognition the parameter τ does not enter in, since each pixel is classified as either containing water (100%) or not (0%). The value of ρ, however, did need to be determined. It was found that the occurrence of false alarms was independent of the value of ρ; therefore, the value of ρ which maximized the detection rate was selected.

Before describing the test results, we present here a brief discussion of the areas which were assigned to each pixel. The instantaneous field of view of the ERTS MSS is 79 m X 79 m but, since the data are oversampled along the scan direction, there is overlap in the ground patch covered by successive samples. Therefore, in order that calculations of the total area of an ERTS frame not exceed the actual area viewed in that frame, a smaller effective size has been used in the scan direction. However, for the problem being addressed here, where the area for only one class in the scene is being estimated, one needs to consider the actual ground area viewed by each pixel. In other words, if a pond smaller than 79 m X 79 m is contained within one pixel and that pixel is estimated to contain 50% water, the estimated area of the pond is 50% of 79 m X 79 m and not 50% of some smaller effective area. Now if this same pond was seen in the overlap area of two successive pixels it would be inaccurate to use the 79 m X 79 m area for each pixel since some portion of the pond would be counted twice.

In order to account for problems of this sort three separate pixel sizes were used in computing estimated area. If the pixel identified as containing some portion of water in excess of the threshold value fell between two pixels on the same scan line which also were identified as containing water, the pixel size for area estimates was assumed to be 79 m X 57 m (the 57 m size was computed based on the 100 nautical mile frame size and number of samples per scan line). "Water" pixels with one "water" neighbor along the scan line were assumed to be 79 m X 68 m and "water" pixels with no "water" neighbors were assumed to be 79 m X 79 m.

Test Results: Using the three processing algorithms described earlier, three water classification maps were generated. These are shown in Figures 4, 5, and 6 for the multichannel proportion estimation, single channel proportion estimation, and conventional recognition algorithms, respectively. The first two maps are printed with symbols whose density is related to the proportion of water estimated in each pixel while the conventional recognition map includes only a single symbol where water was detected implying that the entire ground area viewed in those pixels is covered with water.

Upon comparing Figures 4 through 6 with the aerial photograph in Figure 1 it is clear that the shape of the water bodies was more accurately reproduced on the multichannel proportion estimation map and that more of the small bodies of water are detected on this map. In fact only one of the bodies of water was totally undetected.

In order to compare the area estimation results achieved on individual water bodies using the three algorithms, we present Figure 7. Here we plot on the vertical axis the ratio of area as measured from the photograph to the area determined by automatic processing. On the horizontal axis we plot the shape factor which we define as a constant times the area divided by the perimeter of the water body. Shape factor is used rather than area since water bodies with small shape factors (because of large perimeters or small size) can be expected to be less accurately estimated than those with large shape factors. This expectation is borne out on examining Figure 7 which shows that the spread in accuracy for the three methods is small for water bodies having large shape factors (relatively fewer boundary pixels) and generally increases for smaller shape factors.

The area estimate accuracies are better using the multichannel proportion estimate algorithm in almost every case. There are a small number of cases in which the area is slightly overestimated however it is possible that the areas measured from the aerial photograph were on the low side. In general, the results using the conventional recognition algorithm were much inferior, especially for the smaller shape factor water bodies.

A summary of the results for the entire test site is shown in Table 1. Here we see that 97% of water measured from the photograph was detected using the multichannel proportion estimation algorithm while only about 85% was detected using the other two algorithms. This difference would have been larger if fewer large lakes existed in the scene.

TABLE 1

SUMMARY OF WATER AREA ESTIMATION RESULTS

	Photointerpretation	Fractional Pixel Procedures		Whole Pixel Procedure
		3-Channel Proportion Estimation	1-Channel Proportion Estimation	Conventional Recognition
Number of Water Bodies Detected	19	18	17	13
Total Water Area (Meters^2)	1,041,958	1,006,739	892,118	879,120
Percentage of Photointerpreted Area	100%	97%	86%	84%

We have shown that, for this example, more accurate water surface area estimates are achieved by using multichannel proportion estimation. An example of the successful application of this same technique to a problem in agriculture is described in Reference 3. The problem described there is one of better estimating the area of rice fields in California's Sacramento Valley. Our plans for the coming future are to continue to test the multichannel proportion estimation algorithm on other applications so as to better define its practical utility.

2.2. ASSIGNMENT OF PIXELS TO SPECIFIC ANALYSIS AREAS

It is desirable to evaluate the accuracy of large-area resource surveys made by computer processing of ERTS, or other remote sensor, data. Such evaluations require the checking of recognition results for areas whose identities are known from field observations or other "ground truth" information sources. Even before recognition processing, the training of the classifiers usually involves the use of other areas of known identity that can be located in the remote sensor data.

The location of specific areas and assignment of pixels to individual fields and plots is more of a problem in ERTS data than in airborne scanner data which have finer spatial resolution. For instance, there are less than 600 ERTS pixels per square mile and a maximum of 18* wholly within the boundaries of a 20-acre field. Section and field boundaries are frequently indistinct on ERTS data displays; consequently, errors are made in the visual location of fields and the subsequent assignments of pixels. Pixel misassignments potentially can cause errors in classification results and lead to incorrect conclusions. Even if detected, additional resources are required to correct errors.

Unlike ERTS photographic products, the bulk digital computer-compatible tape (CCT) data are not corrected for any distortions introduced by spacecraft orientation, sensor characteristics, and Earth's rotation. (Bulk data are preferred to precision CCT data for recognition processing because, in the latter, the radiometric accuracy of the data is degraded by re-scanning.) Therefore, when displayed on a line-printer gray-tone map or CRT, substantial distortions are evident in bulk CCT data. Square sections are displayed as parallelograms, and other distortions are present. These distortions increase the difficulty of assigning pixels to specific ground areas, but the major cause of difficulty is the relatively large instantaneous field of view of the MSS scanner.

The problem of correctly assigning ERTS pixels to specific areas is somewhat different from two related problems which are under investigation elsewhere [Refs. 4-9]. Some investigators are studying the cartographic aspects of ERTS data, e.g., image quality and techniques to digitally correct ERTS data to match an Earth coordinate system, using spacecraft attitude information and/or ground control points spread throughout a frame. Others are studying the spatial registration of data from two or more frames that cover the same scene, using ground control points and/or image correlation techniques. The cartographic studies will simplify pixel assignments for areas that are readily identified by their latitude and longitude coordinates, but do not directly address procedures for assigning pixels for areas that are only identifiable on aerial photographs. The spatial registration studies will expedite the transfer of field coordinates from one frame to the next, but again do not consider the problem of initially assigning pixels to fields and test plots.

Techniques for both cartographic correction and spatial registration of ERTS data move data values from their original positions to an overlying grid by nearest-neighbor or interpolation rules. Then, the assignment of pixels to specific fields and test plots can take place; operations on a nearest-neighbor basis increase the uncertainty of true field boundary locations, while interpolation degrades radiometric fidelity. The procedure described here warps Earth coordinates to match ERTS coordinates, effectively computing the location of each pixel, and makes pixel assignments without any movement or interpolation of ERTS data.

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*Even this number is optimistic because the ERTS scan lines do not generally follow field boundaries. Further the oversampling along ERTS scan lines means that there is overlap between the areas viewed by the scanner for adjacent pixels and thus one must move away from boundaries to eliminate their effects.

2.2.1. PROCEDURE

The ERIM procedure [10, 11] for the computer-aided assignment of ERTS pixels relies on an empirical map transformation derived by least squares calculations from a local network of control points in and around the area of interest, e.g., a 20 x 25-km area on a 15' quadrangle map. These control points can be located on topographic maps and/or on aerial photographs. Differing scales can be handled, and the locations of control points and analysis areas on the maps and/or photographs can be obtained on a relative basis.

The empirical transformation produces rotations to account for the non-polar orbit of ERTS and the difference in orientation between Earth and ERTS-data coordinates, and also corrects for effects of the Earth's rotation and other sources of distortion and error, in a least-squares manner.

The computer-aided procedure was developed because it is often difficult to distinguish "by eye" the corners of sections, fields, and plots of interest on digital displays of ERTS data, and more difficult to locate them accurately. Lack of contrast between materials and any banding or striping in the ERTS data can complicate matters. On the other hand, there generally are some road intersections and other features in the scene around and within the areas of interest that can be distinguished readily in digital displays.

In the procedure, we typically select fifteen to twenty distinguishable points as control points and estimate their ERTS line and point numbers as well as possible by inspection. Earth coordinates for the same points are determined* from a topographic map or an aerial photograph. A least-squares fit of Earth to ERTS coordinates reduces the error in the estimated location of each control point and produces a map transformation

$$\begin{bmatrix} P \\ \\ L \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ & \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} X \\ \\ Y \end{bmatrix} + \begin{bmatrix} b_1 \\ \\ b_2 \end{bmatrix}$$

where P and L are the ERTS data coordinates for points along scan lines and for scan lines, respectively,

$\{a_{ij}\}$ are the empirical transformation coefficients,

X and Y are the Earth coordinates to be transformed,

and b_1 and b_2 are the offset parameters to account for different origins.

---

*Digitization is facilitated by the use of an x-y digitizing machine.

(A polynomial transformation has been computed but, thusfar, we have found that terms of higher than first order are not significant.)

The above transformation then is used to transfer Earth coordinates of other points, fields, or plots in the vicinity to their corresponding ERTS coordinates. For several purposes, it has been found convenient to place pixel designation information in a fifth channel added to ERTS data.

A companion computer program allows us to define each training or test area by a polygon with an arbitrary number (≤ 63) of vertices and to compute which ERTS pixel centers lie within the polygon. Further, there is a capability to move the polygon sides in or out by specified distances so as to include or exclude pixels whose signal values include effects of boundaries between scene features, for example, to avoid training on pixels that represent more than one material. An illustration of the effect of this procedure is presented in Figure 8. A section (1 mile square) in actual ERTS data was arbitrarily divided into 16 40-acre "fields". Part(a) of Figure 8 displays as blanks the pixels selected for these fields when the acceptance polygon was inset by one-half a resolution element on all sides.* An average of 22 pixels was selected for each 40-acre field. For Part(b), the inset was increased to three-quarters of a resolution element, and the smaller number of acceptable pixels (an average of 16) in each field is apparent. Parts(c) and (d) show the further reduction in the average number of acceptable pixels to 12 and 5 when the inset is increased to 1 and 1.5 resolution elements, respectively. Figure 9 presents other sets of "fields" delineated by the 0.5 resolution element criterion; field sizes of 640, 160, 80, and 10 acres are shown.

As noted above, the inset of one-half a resolution element is the theoretical minimum needed to exclude pixels whose radiometric signals contain boundary effects. A greater inset probably should be used in practice because of possible errors in the location of the control points in both the ERTS and Earth coordinates and in the location of test plot vertices in the maps or photographs. There also are known displacements inherent in the ERTS data which we presently do not explicitly take into account, e.g., the multiplexer delay in the spacecraft which introduces a displacement between the six scan lines in each mirror sweep.

2.2.2. APPLICATION

A relatively large number of training and test fields were identified manually for use in recognition processing of ERTS-1 data for an agricultural problem, before the computer-aided procedure was developed. Errors in the assignment of pixels to a few fields were identified during the course of the processing. One particular example is presented in Figure 10.

---

*Note that the inset must be greater than one-half a pixel dimension along the scan line since the actual resolution element size is 79 x 79 m even though the sampling rate along the scan lines gives an effective pixel width of approximately 57 m.

Section roads were not always clearly discernible and were not present along all sides of every section, so several section lines were placed on line printer maps by simple interpolation between more distinct roads. The section in question is located on a boundary between two townships and happens to be less than one mile long in the N-S direction. Partly because of the smaller size, the lower section boundary was initially placed below the true boundary. Figure 10a presents the original manual assignment of pixels for four fields; the correct section lines are shown on the line printer map (of ERTS Band 5) and the actual field boundaries, as obtained from an aerial photograph, are mapped on the right. Fields 21, 22, and 23 were originally mis-assigned by the analyst. After poor agreement was observed between recognition results and the assigned crop types, these field délineations were checked and revised manually.

After the computer-aided pixel assignment procedure was developed, it was used to assign pixels to these same fields with a 0.5 resolution element inset. The resulting pixel assignments are presented in Figure 10b. Note the apparent good agreement between the selected pixels and the field boundaries, for example, around the notch in the upper right-hand corner of Field 21 and middle of Field 22. In this example, a USGS topographical map served as the standard coordinate reference for several road intersections that were readily identified in the ERTS data. The derived transformation then was applied to the standard coordinates of the section corners to locate them accurately within the ERTS data. Field vertices were determined relative to these section corners in an aerial photograph taken at the time of the ERTS pass. These relative locations of field vertices then were transformed to ERTS coordinates and pixels were selected.

It is difficult to make a quantitative assessment of the accuracy of our procedure, because of the lack of an absolute knowledge of pixel locations. One attempt was made using a large, distinctively shaped lake because there generally is a large contrast between land and water in ERTS Band 7, so that the accuracy of boundary locations could be assessed. Our goals were (1) to select only those pixels that were completely within the lake and (2) to determine whether map-based coordinates of the shoreline features could be accurately placed in the ERTS data. The results showed that a good job was done in selecting only water pixels and that shoreline features were accurately placed around the lake. The average accuracy of positioning was clearly better than one pixel, but we have not quantitatively determined how much better. The results encourage use of the procedure for processing of ERTS data.

3.0. TECHNIQUES FOR ENHANCING THE EXTRACTION OF LARGE-AREA SURVEY INFORMATION

In this section we discuss two topics which are of importance when considering the monitoring and/or surveying of large areas.

3.1. EXTENSION OF CLASSIFIER SIGNATURES

When large areas are surveyed from space, there exists a high probability that environmental and observational conditions will change from day to day, frame to frame, and/or within a frame. Resulting changes in signal levels received from each class of surface cover can result in degraded machine classification performance and reduced quality of other extracted information. One way to combat such changes is to have available substantial amounts of ground-truth information throughout the survey area; however, this can be expensive. Another way is to adjust the classifier signatures and/or data to counteract the effects of the changes; we call techniques that implement such changes "signature extension" techniques.

In this section, we discuss the improved results obtained with signature extension techniques when signatures extracted from one day were applied to data from the preceding day over the same area. Different amounts of atmospheric haze were present on the two days and the ERTS-1 scan angles were toward opposite sides of the frame. Both an empirical procedure and a theoretical procedure, utilizing calculations of atmospheric effects with a radiative transfer model, were used to adjust Day 1 signatures before they were applied to Day 2 data, and both improved classification accuracy.

The results presented here are from an initial exercise of our signature extension techniques on ERTS-1 data. Only recently did we obtain access to ERTS-1 data sets suited for evaluation of the procedures. We need data on two different days over the same well ground-truthed site, with different amounts of haze present on the two days. A data set, being used in a study in which we are participating under the NASA SR&T program of the Johnson Space Center, met these criteria.

Classifier signatures were obtained for trees and crops on one day and applied directly in processing data from the preceding day. Classification performance was degraded because the different amount of haze present and different observation geometries changed the magnitude and spectrum of the signals received by ERTS-1. By applying certain signature extension procedures, we were able to adjust the signatures used, improve the classification performance, and, thereby, extend the original signatures to the second day.

To help describe the signature extension techniques employed, the following example of tree recognition is given. First, an area that was 100% classified as trees on the first day was found and outlined on a recognition map. When the Day 1 signatures were applied to the Day 2 data, only 67% of the picture elements (pixels) were correctly classified as trees (symbol θ on Figure 11a). Then the signatures were adjusted by an amount determined by subtracting the mean level of signals over a larger nearby area on Day 1 from the mean levels computed for the same area on Day 2. A different adjustment was made for each channel. The adjusted signatures were used in the classifier and the classification percentage increased to 77% (Figure 11b).

Photometer readings had been made on the two days at the time of the ERTS passes. These readings were used to calculate an optical depth at each wavelength for each day. Dr. Robert Turner of ERIM used his radiative transfer model [12] to compute total radiance and path radiance quantities for those optical depths and observation geometries. We then computed signature adjustments based on the model calculations and applied them to the Day 2 data. The result, shown in Figure 11c, is that 88% of the pixels in the area were classified as trees.

The above example is one of the more dramatic cases observed but, nevertheless, is indicative of the trend. The centers of a total of 27 wooded areas were delineated and tested. As shown in Table 2, the average classification accuracy fell from 96% to 88% for no adjustment of the signatures. The two signature extension techniques increased the correct classification accuracies to 92% and 91%, respectively.

TABLE 2

SUMMARY OF CLASSIFICATION RESULTS FOR ONE AREA VIEWED ON TWO SUCCESSIVE DAYS

SIGNATURES	DATA SET	WHEAT % CORRECT	TREES % CORRECT
DAY 1	DAY 1	87%	96%
DAY 1	DAY 2	65%	88%
DAY 1*	DAY 2	71%	92%
DAY 1**	DAY 2	78%	91%
NO. TEST AREAS		10	27

*EMPIRICAL MEAN LEVEL ADJUSTMENT

**THEORETICAL LEVEL ADJUSTMENT (Photometer Plus Model)

Results for field-center pixels of ten wheat fields also are presented in Table 2. Here, again, the accuracy fell from 87% to 65% with no adjustment, and rose to 71% and 78% for the two types of signature extension procedures.

These preliminary results, in our opinion, demonstrate that the atmosphere poses a problem for accurate machine classification with ERTS data over large areas and indicate that steps can be taken to alleviate the degrading effects of the atmosphere. However, more analysis is required to obtain a better understanding of the sensitivity of classification results to signature adjustments and other signature extension procedures and to develop efficient and accurate procedures for determining and implementing corrections. The next section discusses some of the insights gained to date regarding the atmospheric effects.

3.2. ANALYSIS OF ATMOSPHERIC EFFECTS

The atmosphere significantly affects the amount of energy received at the ERTS satellite, both with an additive path radiance term and an attenuating effect on signals from the Earth's surface. As seen in Figure 12, path radiance constitutes over 50% of the signal from an 8% reflector in ERTS Band 4 (i.e., at 0.55 μm) and, proportionately, it is even greater in signals from darker surfaces. Although atmospheric effects are reduced at the longer wavelengths of ERTS Bands 6 and 7, they still are significant. Some indications of the relative magnitudes were presented in our earlier paper at the ERTS Symposium in March, 1973 [2].

Figure 12 also was presented in the March paper, but is repeated here because it exhibits some of the major dependencies of path radiance and total radiance that are pertinent to a discussion of signature extension over large areas. It represents calculations made with the radiative transfer model. First, we see that the path radiance depends upon the amount of atmospheric haze present, here denoted by horizontal visual range. The effect of haze on total radiance at the satellite is less than on path radiance, because of the compensating effects of atmospheric transmittance which decreases as the amount of haze increases.

The other important effect in Figure 12 is the scan angle effect. There is a tendency to dismiss scan angle as being an unimportant consideration in ERTS data, because the scan is only ±5.5° from nadir and frequently only fractions of frames are analyzed. However, the theoretical calculations shown here have a noticeable scan angle dependence from one side of a frame to the other, an effect which is intensified by an increase of haze.

For the data set described in Section 3.1, the scene was viewed approximately 4° to the East of nadir on Day 1 and 3° to the West of nadir on Day 2. Photometer readings were used to establish optical depth vs. wavelength profiles for the two days. These profiles differed from our standard atmospheres which are labeled by horizontal visual ranges. Visibility readings of 19 km and 24 km were recorded at airports in the vicinity. Theoretical radiative transfer model calculations for an assumed average background albedo distribution resulted in a signature adjustment vector that includes effects for the differences in both optical depth and scan angle, and its application resulted in the improved classification accuracy already noted, even though its magnitude is only a few percent (or less) of the average signal value in each band.

Another important factor in path radiance is the average background surface albedo that applies for any given observation. Figure 13 illustrates how surface albedo affects the variations in received signals at 0.55 μm (Band 4). It is very interesting that, for low albedo, an increase in haze (shorter visual range) can decrease the signal in space, while the opposite effect is true for high albedos.

We intend to examine in more detail the sensitivity of classification performance to adjustments of signatures, in an effort to improve procedures. While the signature adjustment procedure effectively applies the same correction to all signals, independent of their magnitudes, a more general procedure would apply to each observation a preprocessing transformation that could depend on the signal magnitude.

Another preprocessing transformation that we have applied to aircraft multispectral scanner data for several years [13], and more recently to ERTS data [14], is ratio preprocessing, i.e., the computation of ratios of signals in different channels for use as classifier inputs and/or for image enhancement. Ratios of signals are more closely related to ratios of spectral reflectances of scene objects if path radiance contributions are subtracted before the ratios are computed. One method developed at ERIM for approximating path radiance is the use of the lowest bonifide signal level in each band. In Bands 6 and 7, water signals are usually the lowest received. Figure 14 presents a manual contour of water signals extracted for Band 6 from approximately 30 water bodies throughout one frame. The dots indicate the sample points and the contour numbers are ERTS data values. The contour pattern agrees with the pattern of airport visibility readings from the five cities noted on the frame.

4.0. CONCLUSIONS

In conclusion, we have discussed several techniques which potentially can improve the quality and quantity of information extracted from ERTS data. We believe that the continued development of interpretive techniques and their incorporation into applications efforts in many disciplines is important to the success of operational Earth Observation systems.

ACKNOWLEDGEMENTS

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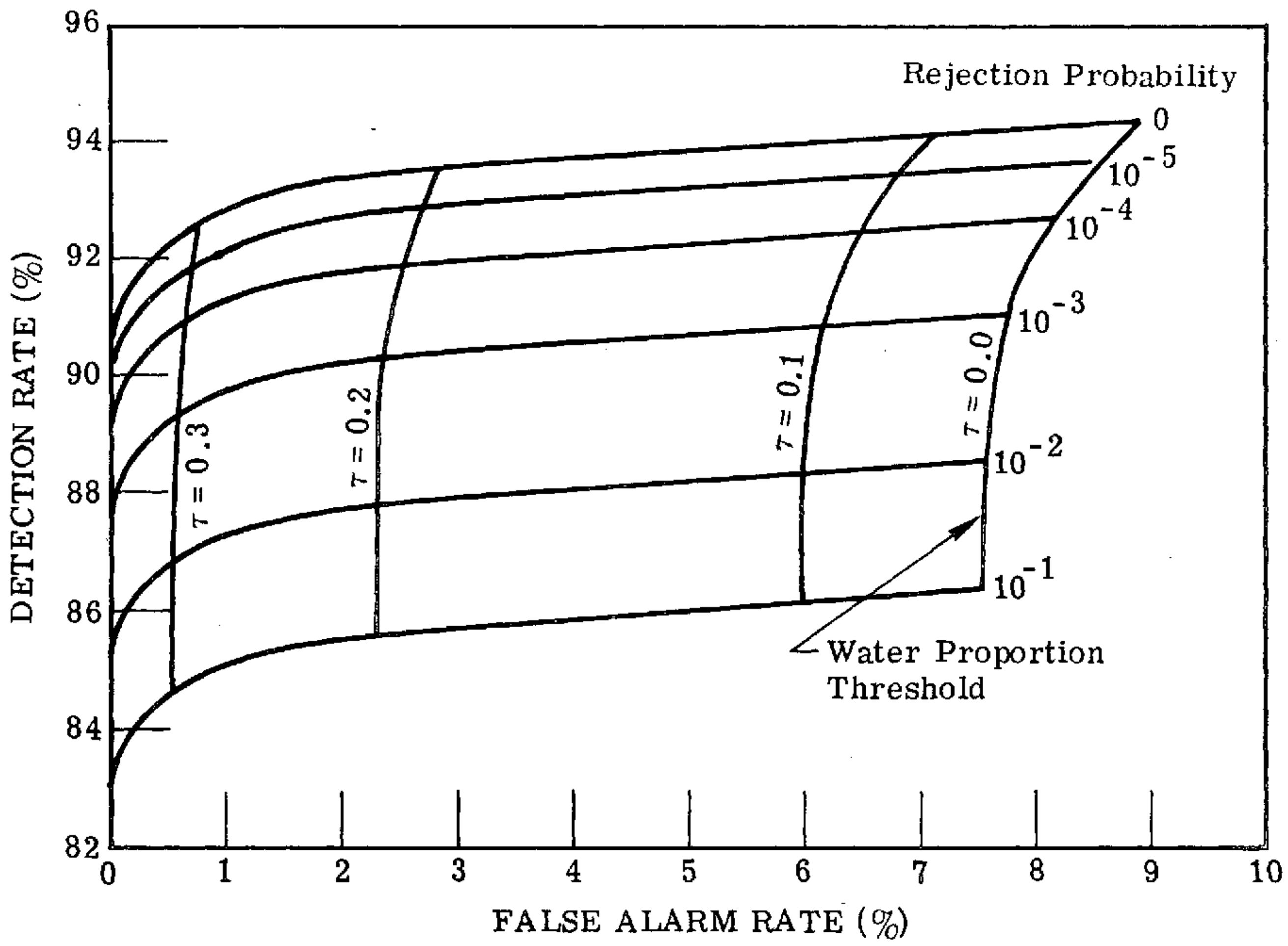
FIGURE 1

TEST AREA FOR PROPORTION ESTIMATION

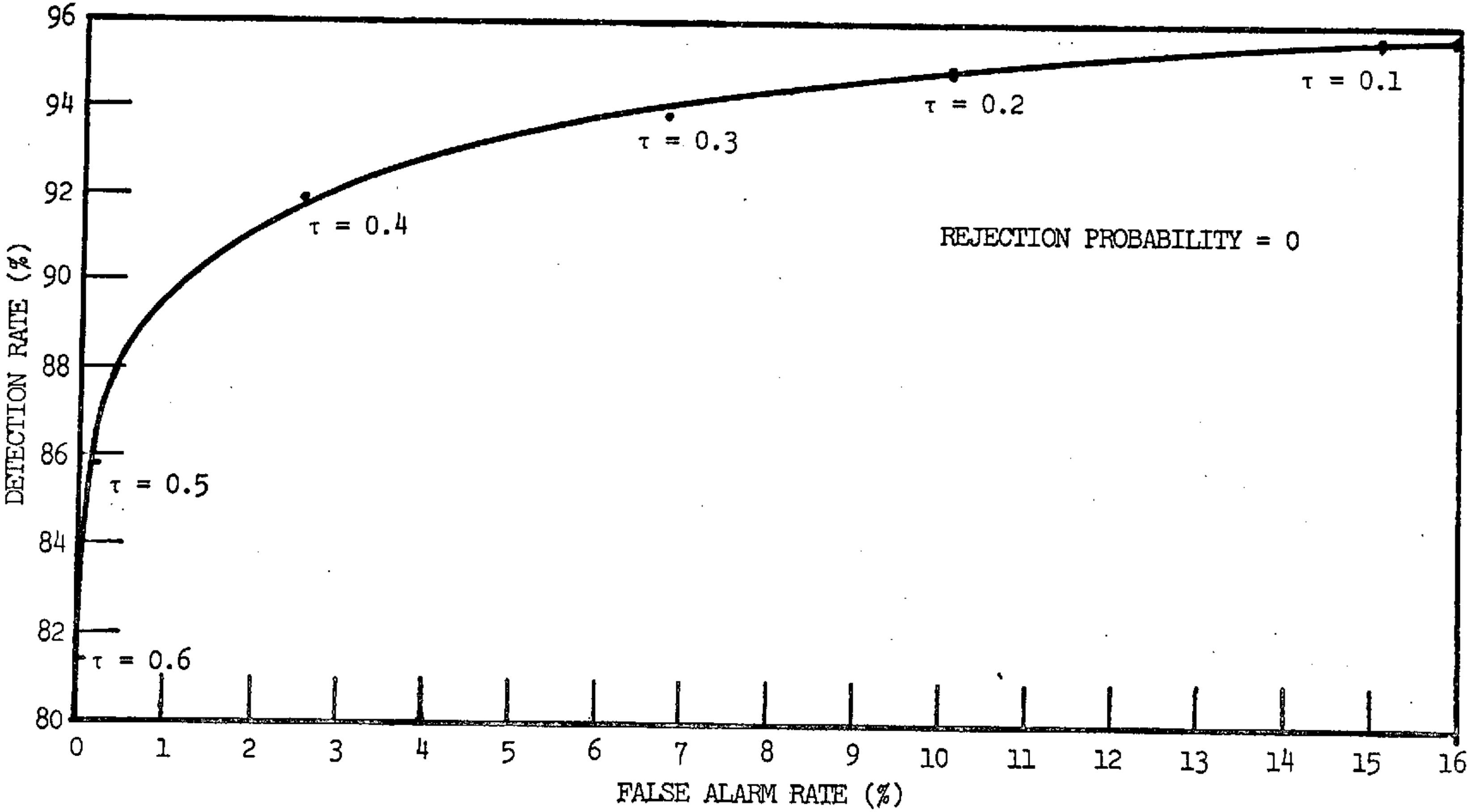
ERIM



OPERATING CHARACTERISTICS OF PROPORTION ESTIMATION (3 channel)

FIGURE 2

ERIM



OPERATING CHARACTERISTICS OF PROPORTION ESTIMATION (1 CHANNEL - ERTS BAND 7)

FIGURE 3

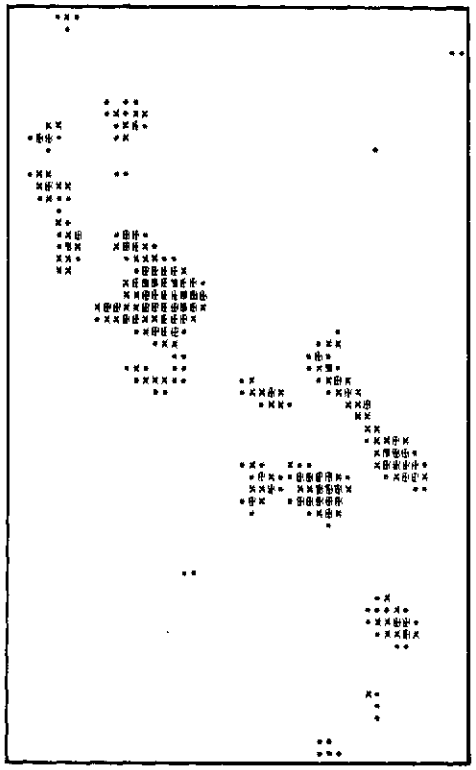
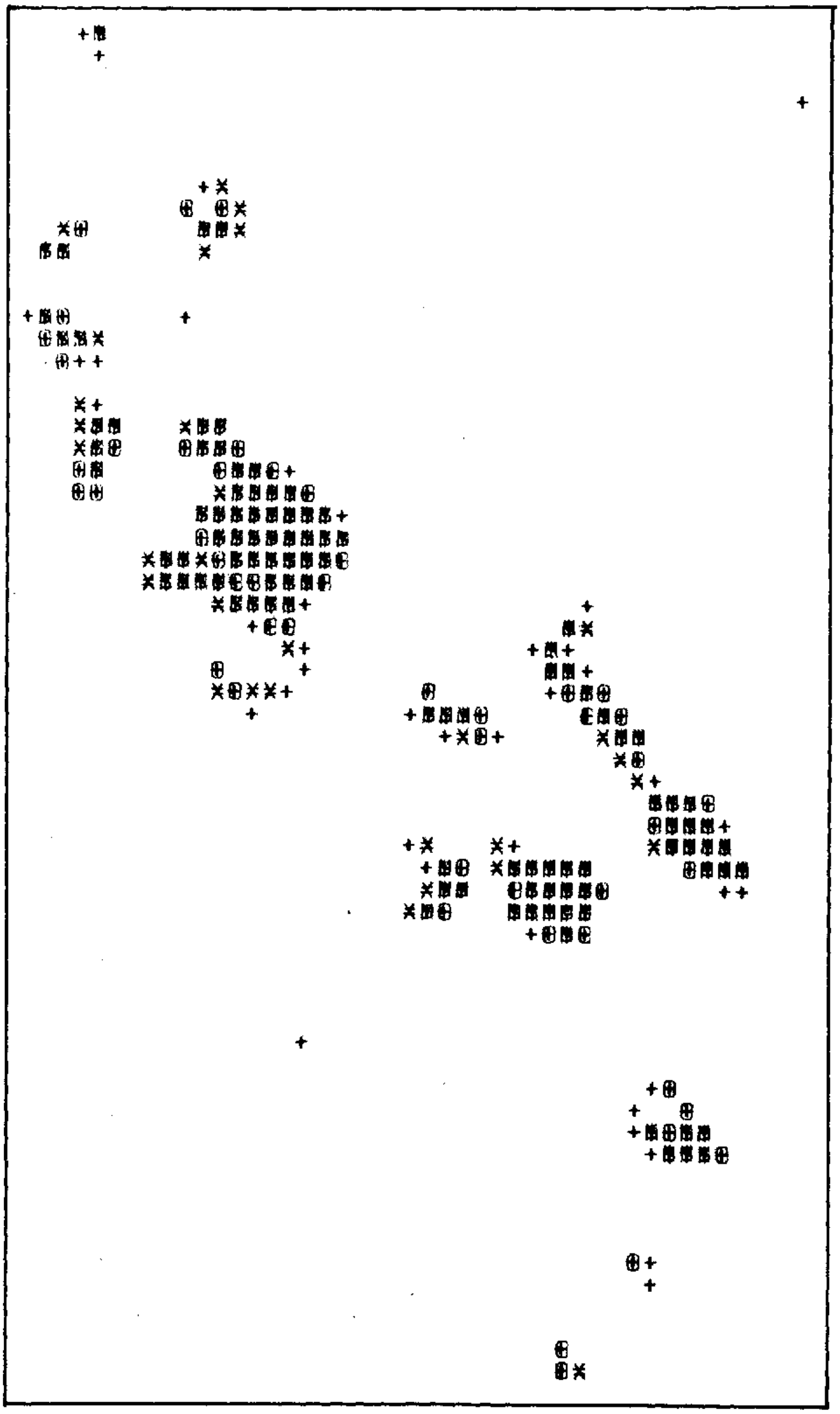


FIGURE 4

PROPORTION ESTIMATE
WATER RECOGNITION MAP
(with ERTS Bands
4, 5, and 7)

ERIM



PROPORTION ESTIMATE
WATER RECOGNITION MAP
(With ERTS Band 7 Only)

FIGURE 5

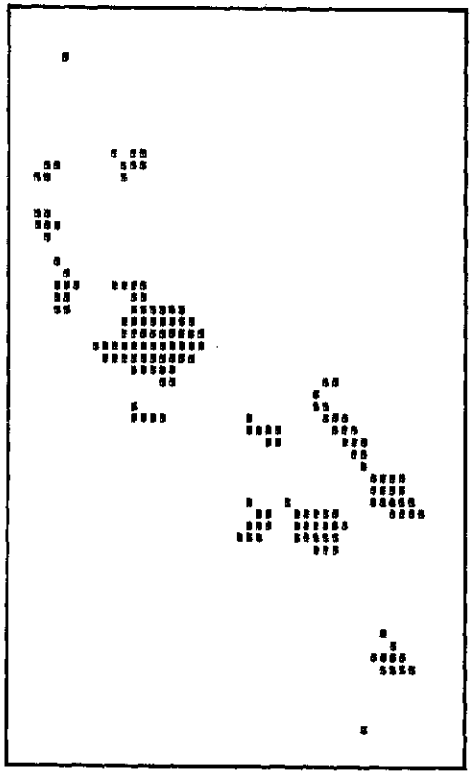
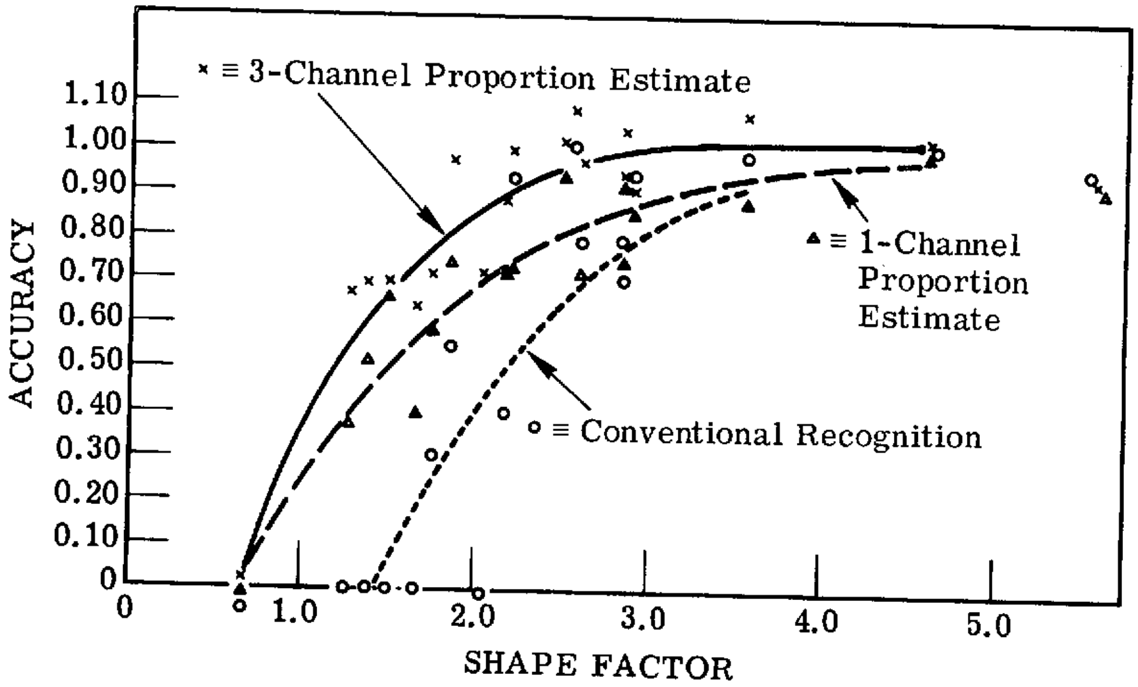


FIGURE 6

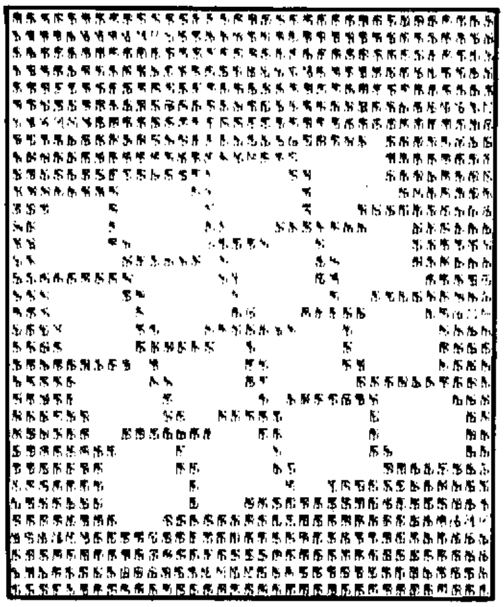
CONVENTIONAL WATER RECOGNITION MAP (with ERTS Bands 4, 5, and 7)



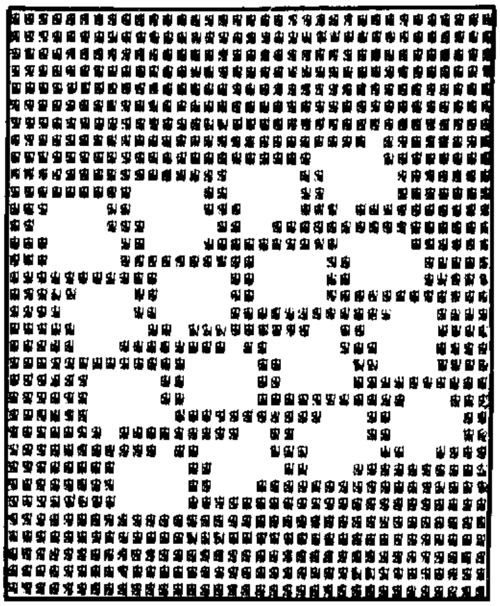
COMPARISON OF EFFECT OF SHAPE FACTOR ON AREA ESTIMATION OF WATER BODIES

FIGURE 7

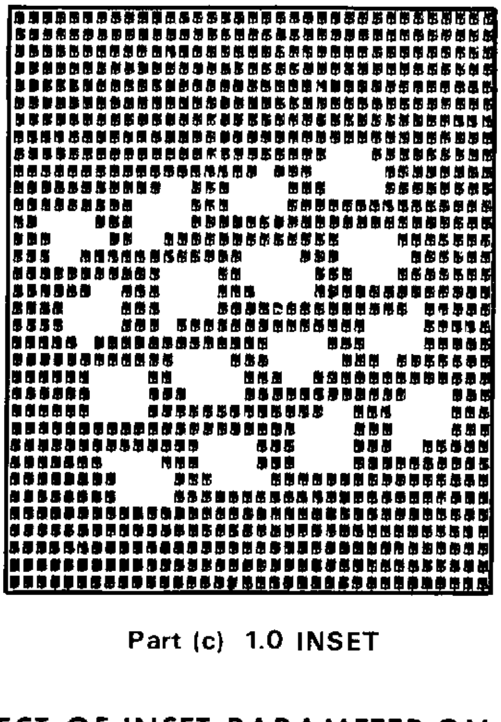
ERIM



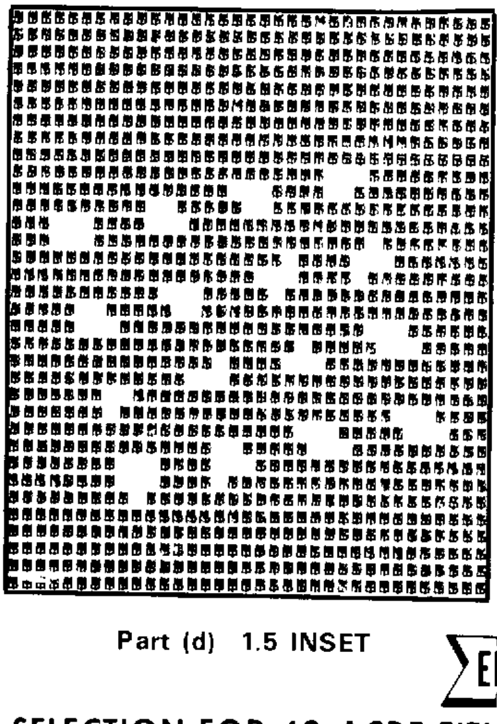
Part (a) 0.5 INSET



Part (b) 0.75 INSET



Part (c) 1.0 INSET

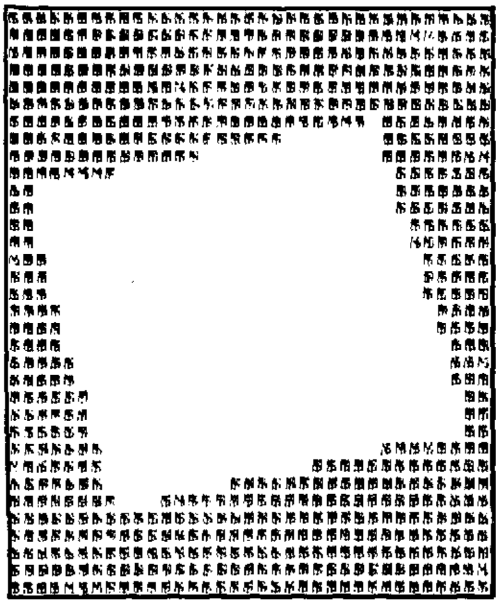


Part (d) 1.5 INSET

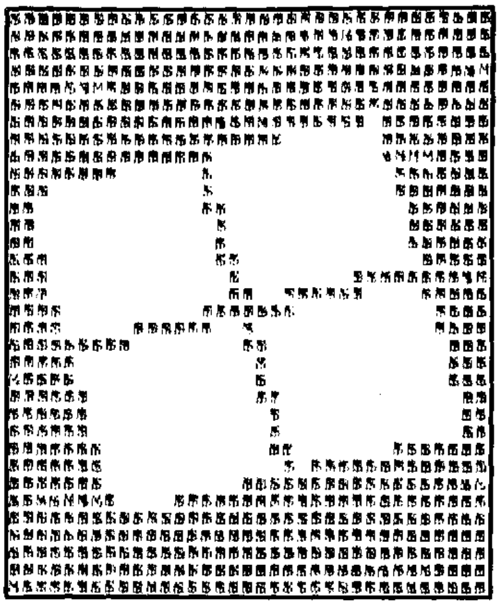
EFFECT OF INSET PARAMETER ON PIXEL SELECTION FOR 40-ACRE FIELDS

(Inset Parameter is Measured in MSS Resolution Elements)

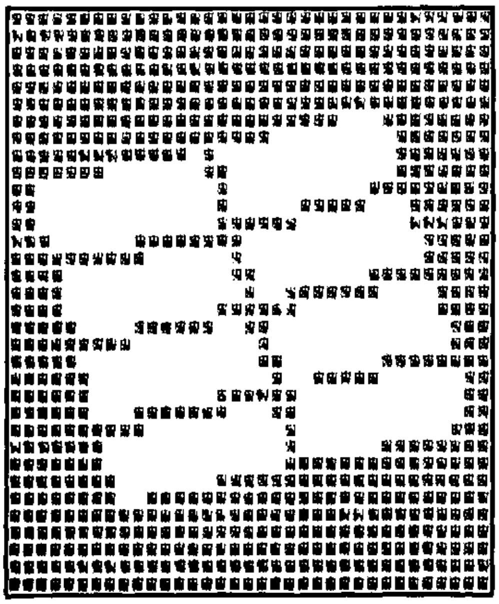
FIGURE 8



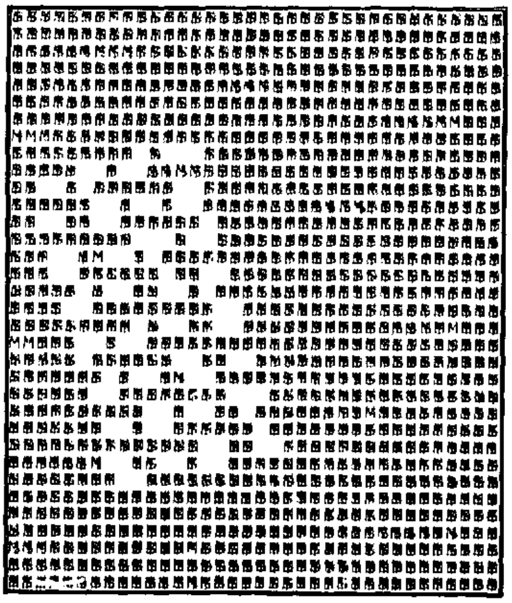
640 ACRE FIELD



160 ACRE FIELDS



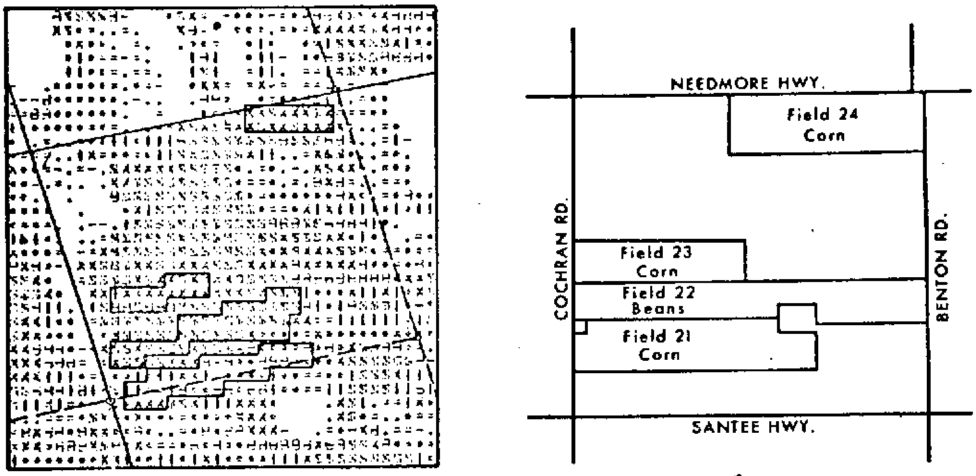
80 ACRE FIELDS



10 ACRE FIELDS

EFFECT OF FIELD SIZE ON PIXEL SELECTION FOR 0.5-RESOLUTION-ELEMENT INSET

FIGURE 9

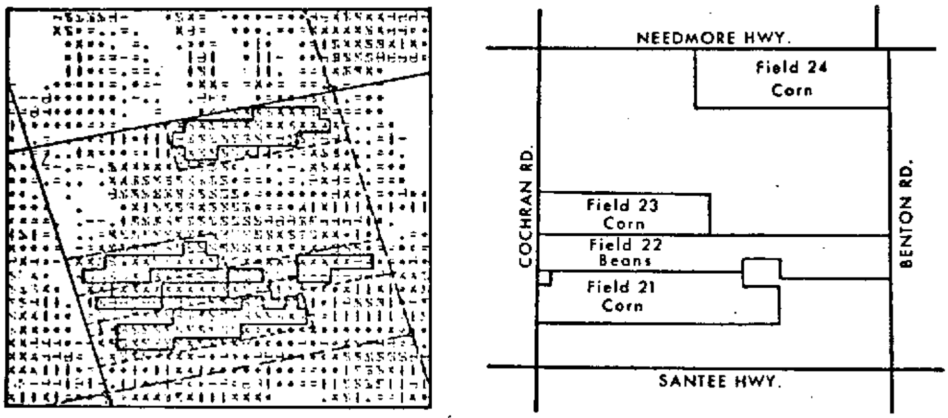


ORIGINAL MANUAL ASSIGNMENT

MAP OF FIELD BOUNDARIES

EXAMPLE OF FIELD LOCATION IN ERTS DATA

FIGURE 10a



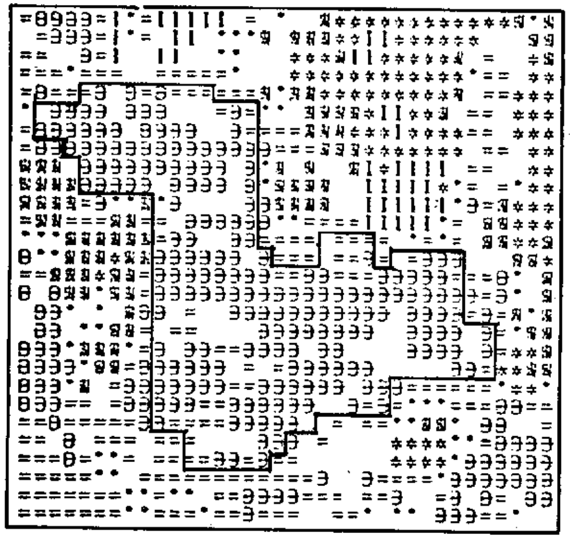
COMPUTER-AIDED ASSIGNMENT

MAP OF FIELD BOUNDARIES

EXAMPLE OF FIELD LOCATION IN ERTS DATA

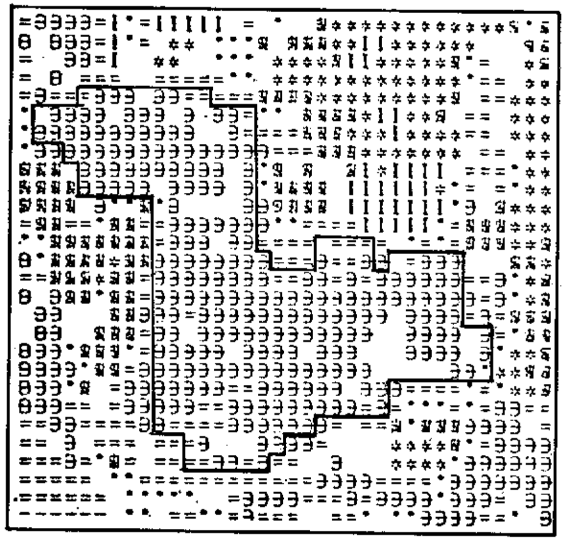
FIGURE 10b

ERIM



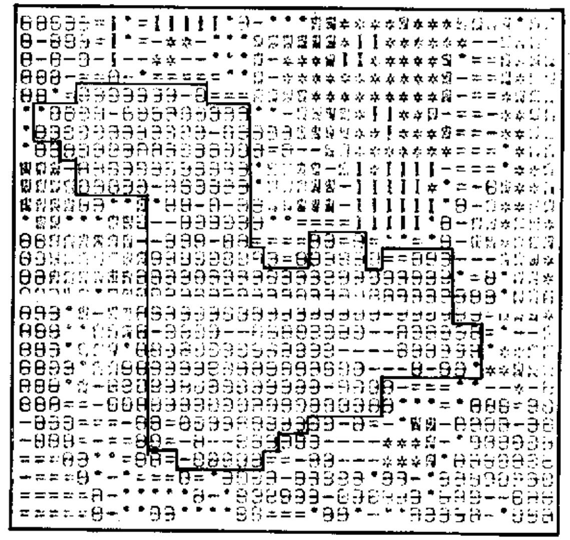
NO ADJUSTMENT OF SIGNATURES

(67% Called Trees)
(a)



EMPIRICAL MEAN LEVEL ADJUSTMENT

(77% Called Trees)
(b)



THEORETICAL MEAN LEVEL ADJUSTMENT

(88% Called Trees)
(c)

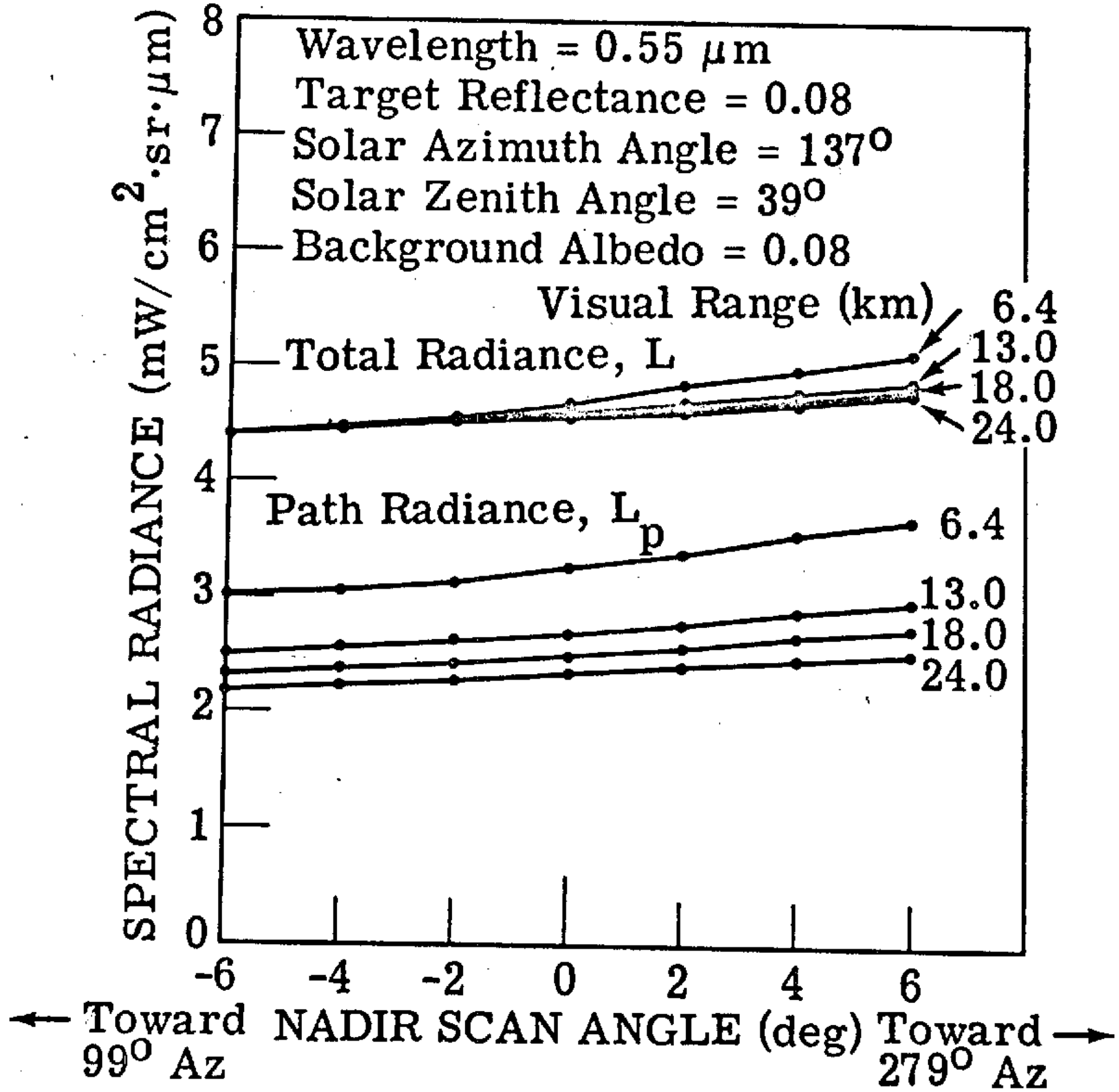
Outlined Area Completely Recognized as Trees for Same Day as Signatures.

EXAMPLE OF APPLYING SIGNATURES FROM ONE DAY TO ERTS DATA FROM PRECEDING DAY OVER SAME AREA

FIGURE 11

FIGURE 12

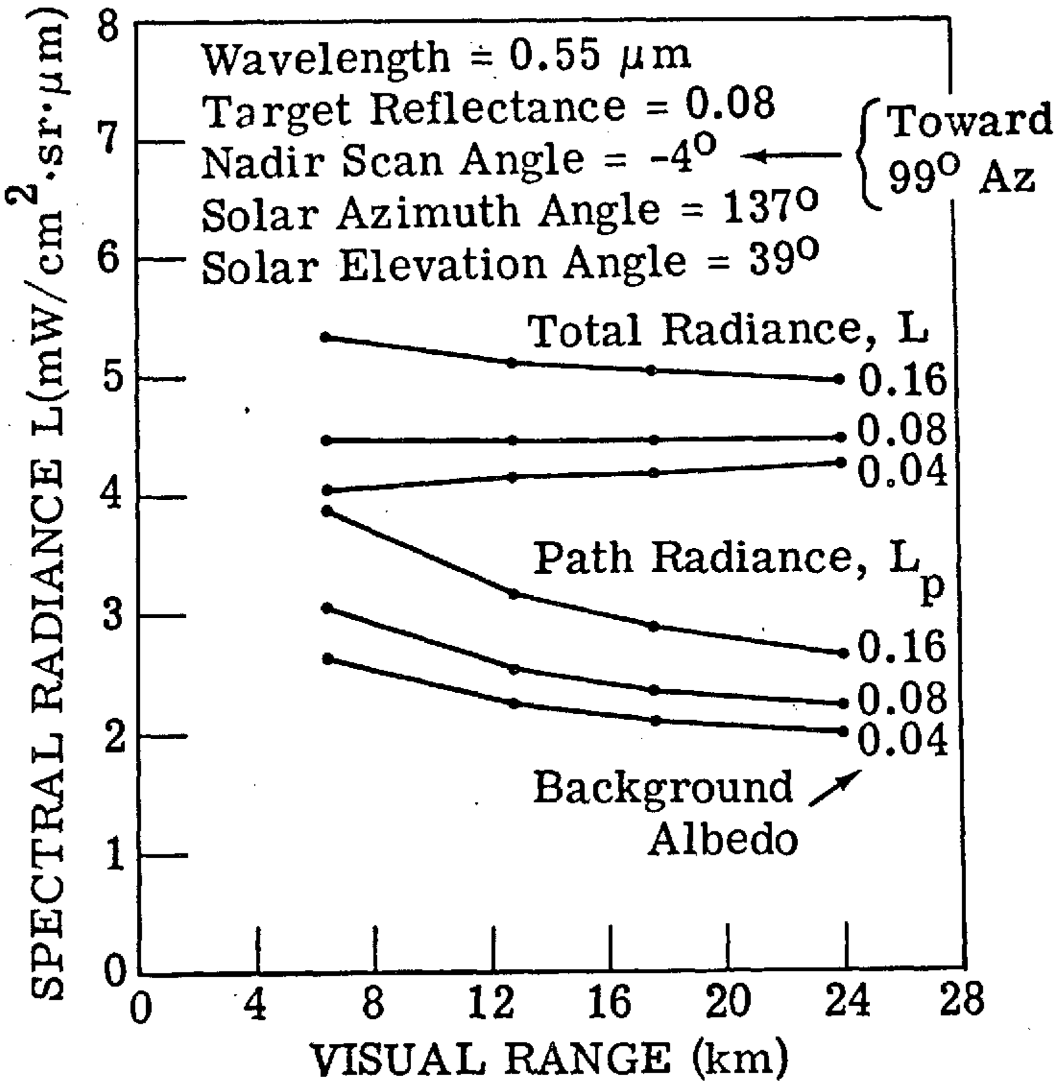
COMBINED SCAN-ANGLE AND VISUAL-RANGE EFFECTS ON RADIANCE AT SATELLITE, 0.55 μm



ERIM

FIGURE 13

DEPENDENCE OF RADIATION AT SATELLITE ON VISUAL RANGE, 0.55 μm



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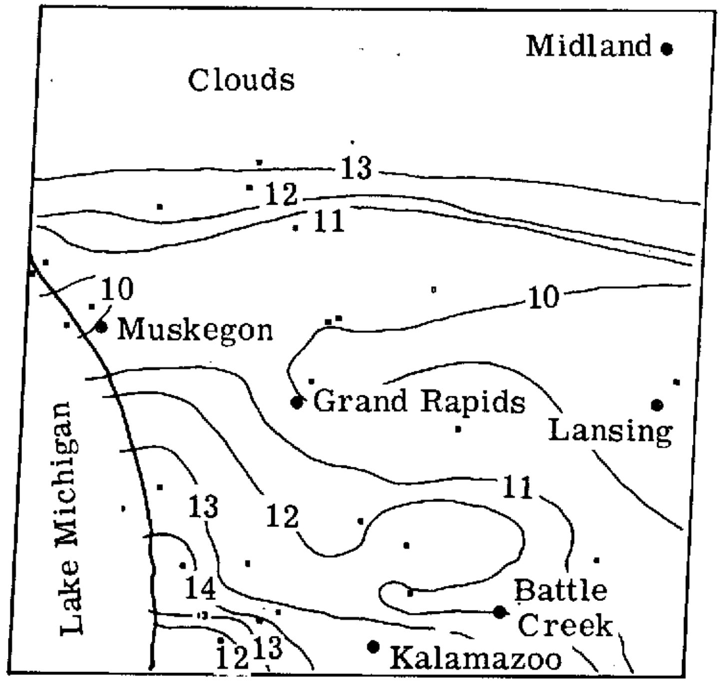


WATER SIGNAL CONTOURS, ERTS Band 6
(Frame 1033-15580)

FIGURE 14

Third Type II Progress Report
C.T. Wezernak, MMC 081
Task VIII, Water Quality Monitoring

INTRODUCTION

Work performed during the reporting period 1 July - 31 December 1973 was directed largely towards investigating the quantitative relationship between near-surface suspended solids concentrations (Total Non-filterable Residue) and ERTS digital integer levels in MSS 5. Analyses of data for the western basin of Lake Erie, New York Bight, and the Michigan-Indiana shore of Lake Michigan were performed.

PROGRESS

The introduction of particulates into a body of water will result in the alteration of the reflectance spectra of the receiving waters in the manner shown in Figure 1. The illustration represents the case in which the receiving waters are clear, free of other pollutants, and of sufficient depth so that bottom reflectance is not a factor. Admittedly, the curves represent a somewhat simple and "ideal" case. However, the major point to be drawn from the curves is the fact that a major change in the reflectance spectra occurs in the 0.6 μm - 0.7 μm spectral band (MSS 5). The relationship shown is not linear and represents both particle size and concentration. Beyond 0.7 μm the curves for inorganic particulates will drop off. Additionally the attenuation coefficient in the near-infrared will increase rapidly limiting observations to essentially the water surface.

Shown in Figure 2 is the expected spectral response for a body of water which contains varying concentrations of phytoplankton. The nature of the response in MSS 5 is due to the fact that phytoplankton are "particulates" and to the presence of photosynthetic pigments. Also it should be noted that the curves increase in the near-infrared for phytoplankton whereas a decrease occurs in the case of inorganic particles.

The foregoing remarks are presented simply to underscore the fact that in principle a basis exists for detecting suspended solids variation and delineating phytoplankton blooms using ERTS spectral bands. In practice, however the success achieved will be governed by the characteristics of the instrumental system and atmospheric conditions at the time of data collection. Although in Figure 2 an increased reflectance in MSS 4 is indicated, atmospheric attenuation generally limits the utility of this spectral band in the Great Lakes and New York areas.

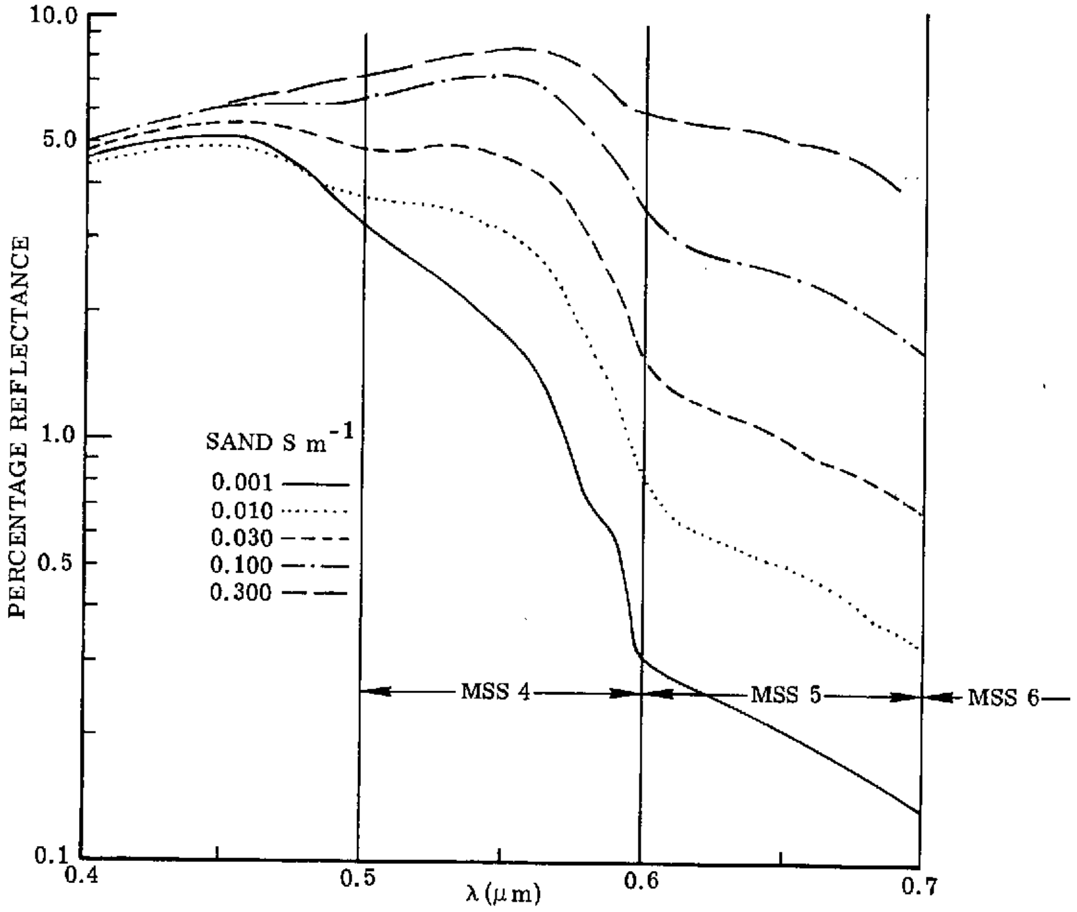


FIGURE 1. CALCULATED CHANGE IN REFLECTANCE OF WATER WITH INCREASING CONCENTRATION OF SUSPENDED SOLIDS*

*After G. Suits, ERIM.

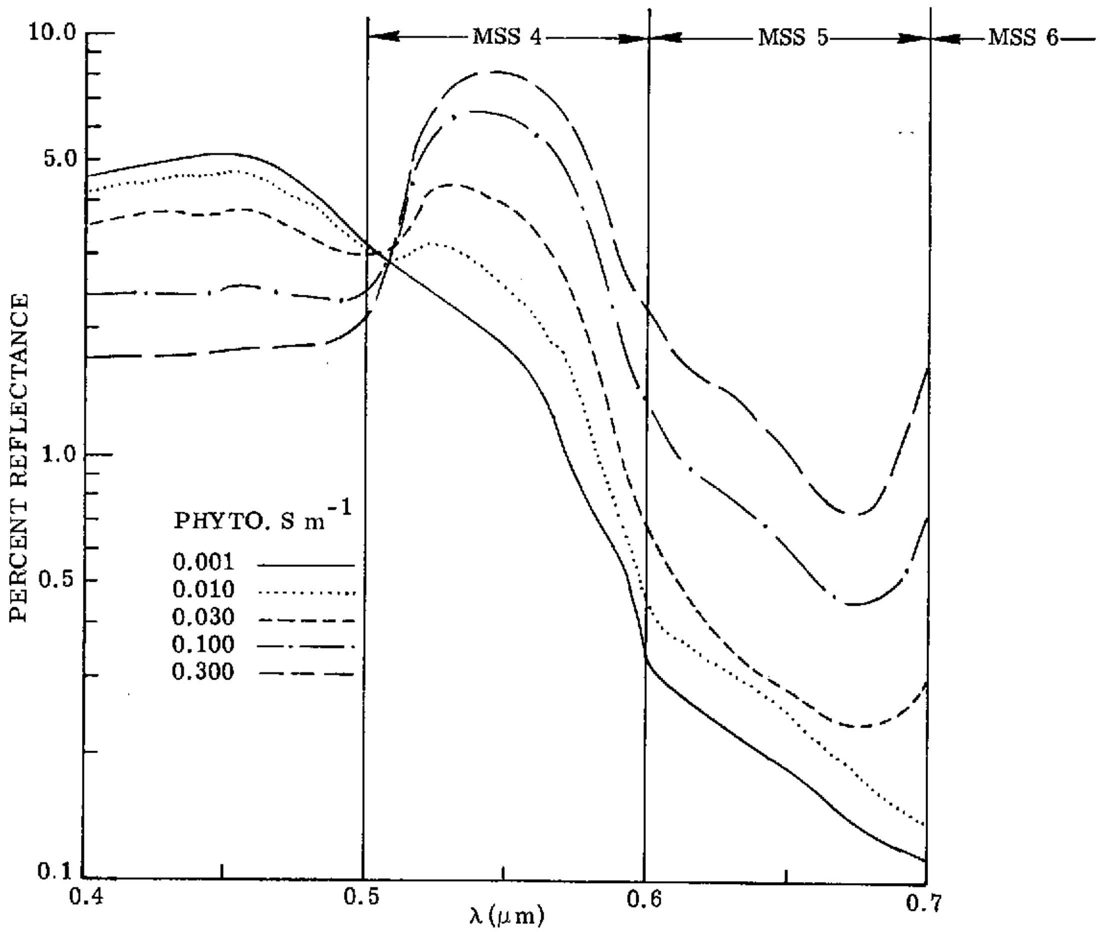


FIGURE 2. CALCULATED CHANGE IN REFLECTANCE OF WATER WITH INCREASING CONCENTRATION OF PHYTOPLANKTON*

*After G. Suits, ERIM.

Western Basin Lake Erie

Digital processing of ERTS data for the western basin of Lake Erie has been performed. Frames 1247-15481 (27 March 1973) and 1319-15474 (7 June 1973) have been processed. Analysis of individual lines at two selected transects has also been performed to determine correlation between digital integer level in MSS 5 and relative concentration of suspended solids. Figures 3 and 4 illustrate the investigative approach being utilized. A digital map of the scene is shown in Figure 5. Figure 4 represents an average of four lines and indicates a relationship between suspended solids and digital integer level.

Experiences with E-1247-15481-5 and E-1319-15474-5 data indicate a relationship which takes the following form for the concentration range of 50 mg/l and less:

$$\log C = \log a + b \log V$$

where:

C = concentration

a,b = constants

V = voltage value (data value)

A continued analysis of data is required to develop procedures for normalizing data collected on different scene dates, to account for the varying integration associated with light penetration to different depths, and to evaluate constants.

Work in the western basin of Lake Erie is being coordinated with the work of the Grosse Ile Laboratory of the Environmental Protection Agency.

New York Bight

Digital processing of ERTS frame E-1258-15082 was performed (Figure 6). Additionally, a statistical analysis of digital data dealing with major areas of interest in frames E-1258-15082 (7 April 1973) and E-1024-15071 (16 August 1972) was performed. The results of the analyses are presented in Figures 7 and 8.

The data values shown represent the mean of several hundred points in the scene for the major target areas. Tentative results indicate that a suspended solids loading of 5 mg/ℓ above background results in an increase in digital integer level of 3 in MSS 5. Allowing for a noise level (of ±1 integers along a line) indicates that the minimum detectable concentration difference is approximately 5 mg/ℓ. In view of the fact that particle size is a factor in the resulting spectral response, the foregoing empirical results apply only to this study location. Additional analyses of the data are required.

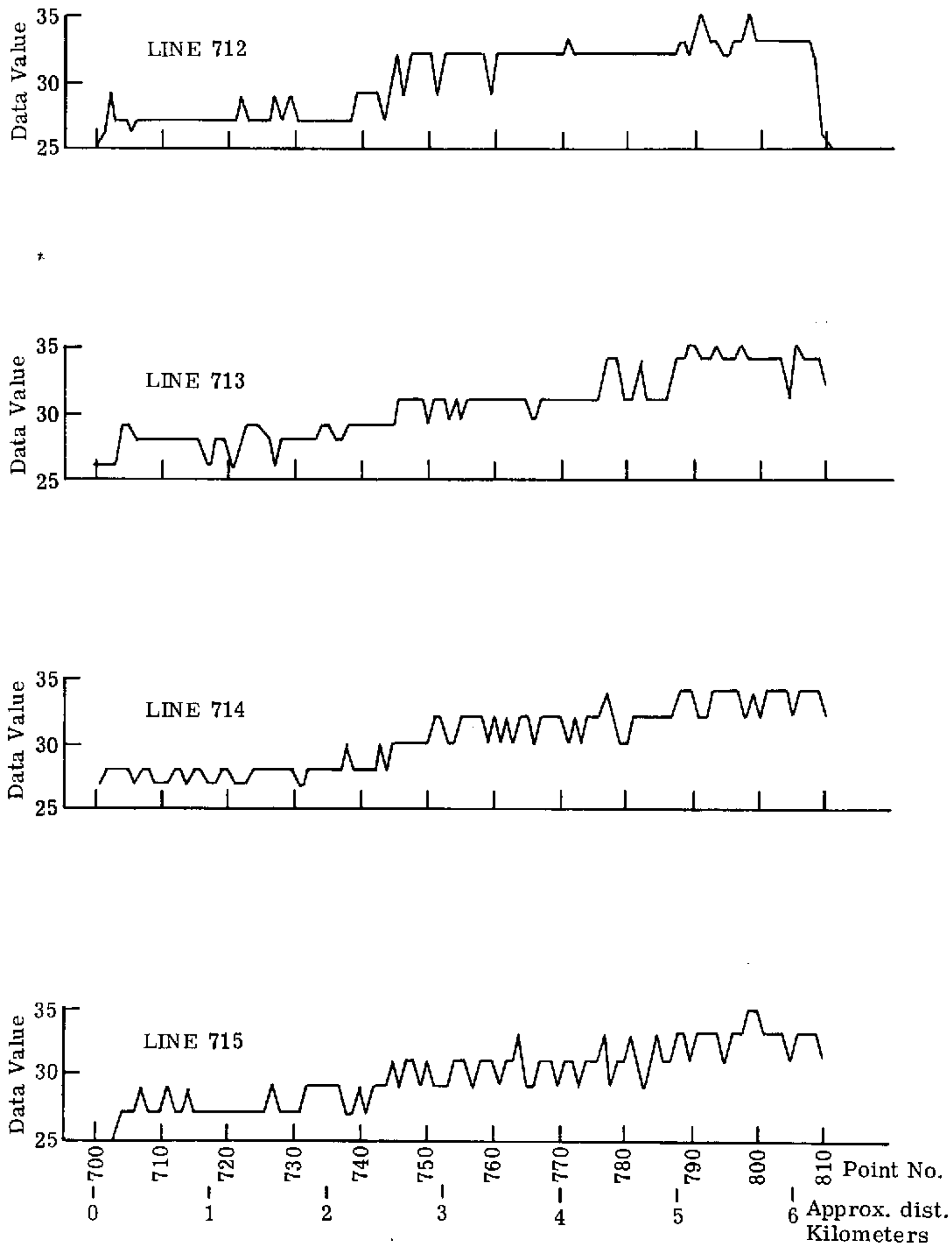


FIGURE 3. DETROIT RIVER TRANSECT ERTS DATA VALUES, MSS 5, 27 MARCH 1973
E1247-15481

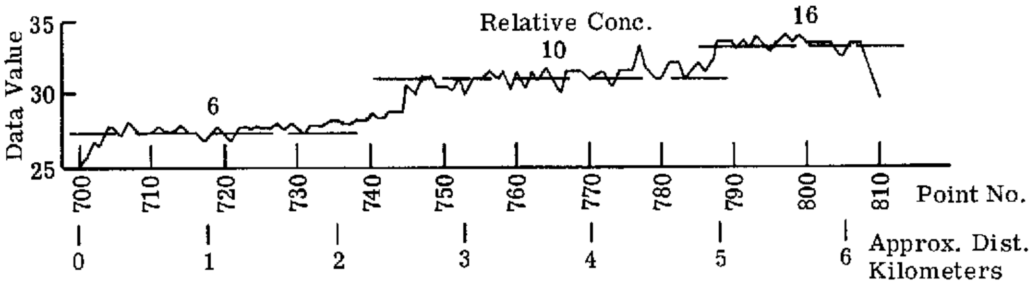


FIGURE 4. DETROIT RIVER TRANSECT SUSPENDED SOLIDS VS ERTS DATA VALUE MSS 5, 27 MARCH 1973, E1247-15481. Average of four lines. 240,000 cfs.

FIGURE 5. LAKE ERIE, 27 MARCH 1973. ERTS-1 data, E-1247-15481-5

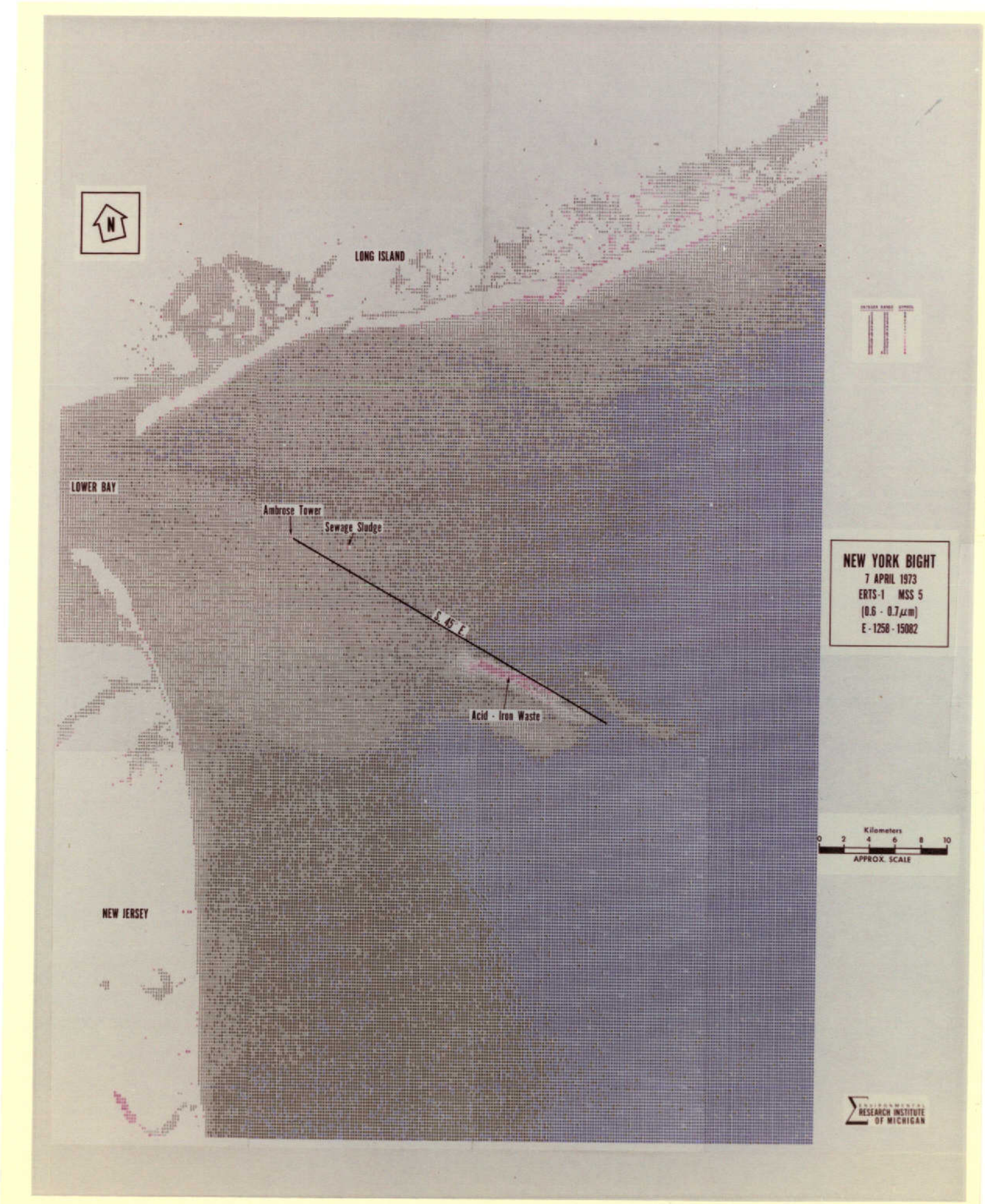
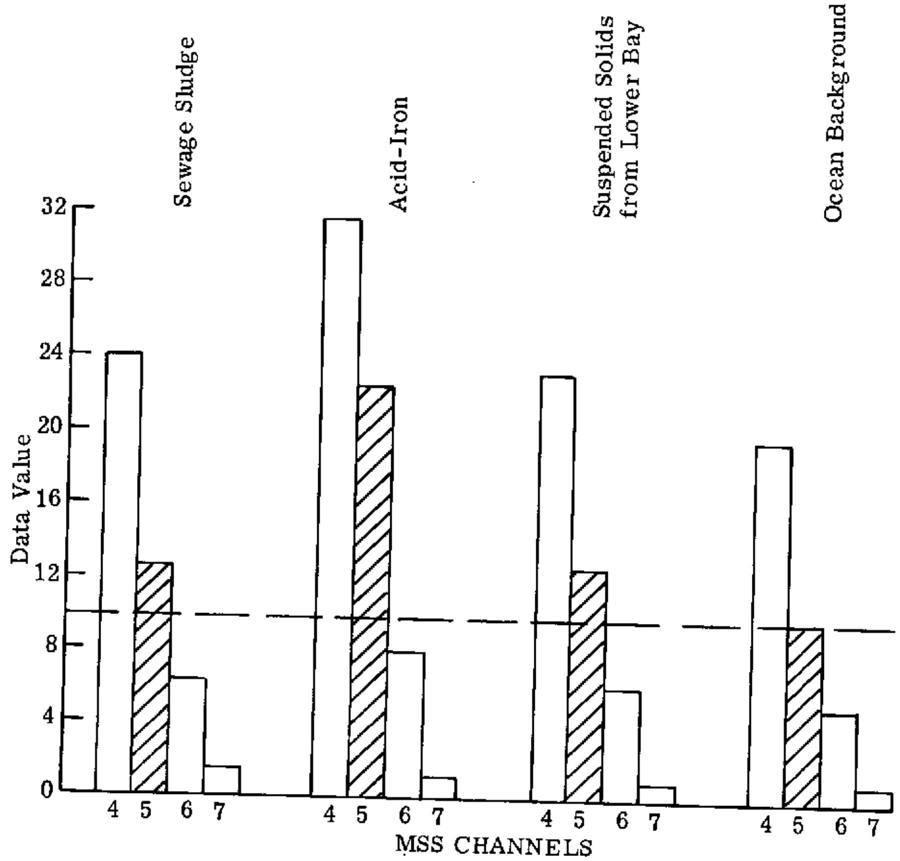
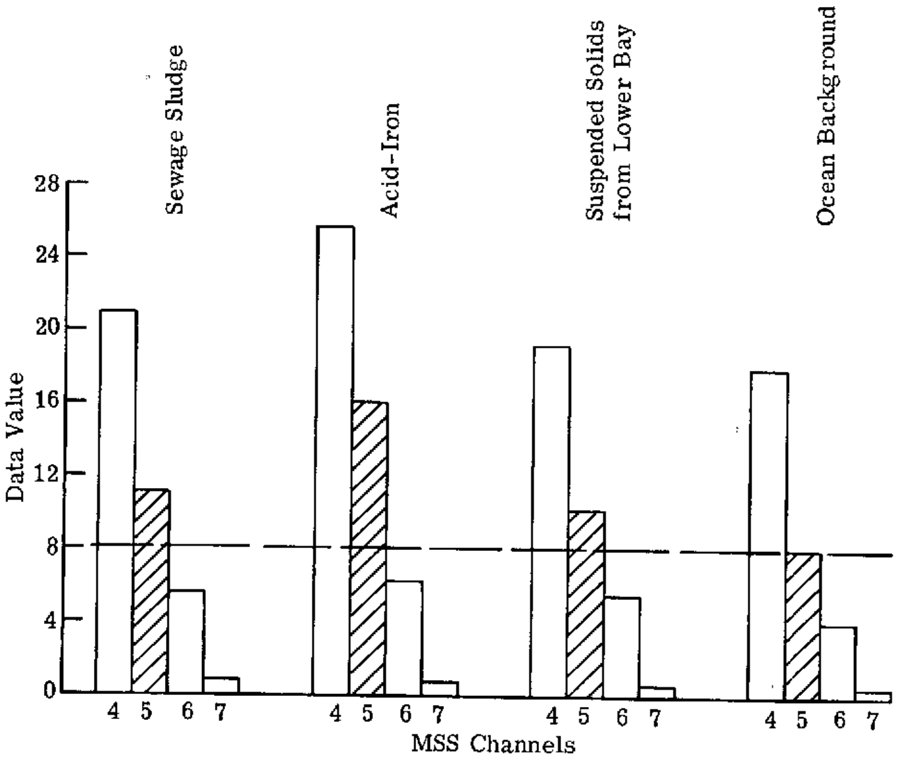

N
LONG ISLAND
LOWER BAY
Ambrose Tower
Sewage Sludge
S 45 E
Acid - Iron Waste
NEW JERSEY
NEW YORK BIGHT
7 APRIL 1973
ERTS-1 MSS 5
(0.6 - 0.7μm)
E-1258-15082
Kilometers
0 2 4 6 8 10
APPROX. SCALE
ENVIRONMENTAL RESEARCH INSTITUTE OF MICHIGAN

FIGURE 6



	Channel	Data Value Mean	Std. Dev.
Sew. Sludge	4	24.15	0.38
	5	12.54	0.52
	6	6.15	0.38
	7	1.54	0.52
Acid-Iron	4	31.76	1.21
	5	22.56	1.63
	6	8.02	0.90
	7	1.16	0.51
Lower Bay	4	23.38	0.93
	5	12.73	0.71
	6	6.18	0.73
	7	0.93	0.55
Ocean	4	19.82	0.54
	5	9.79	0.72
	6	5.33	0.67
	7	0.87	0.57

FIGURE 7. ERTS DATA NEW YORK BIGHT, 7 APRIL 1973, E1258-15082



	Channel	Data Value Mean	Std. Dev.
Sew. Sludge	4	20.97	1.73
	5	11.08	0.97
	6	5.50	1.58
	7	0.77	0.66
Acid-Iron	4	25.82	1.07
	5	16.22	1.79
	6	6.31	0.86
	7	0.70	0.56
Lower Bay	4	19.24	0.77
	5	10.20	0.69
	6	5.49	0.63
	7	0.64	0.57
Ocean	4	18.03	
	5	7.97	
	6	4.10	
	7	0.46	

FIGURE 8. ERTS DATA NEW YORK BIGHT, 16 AUGUST, 1972, E1024-15071

Reflectance calculations were performed for the major target areas in the scene using ERTS-1 and aircraft data. The resulting ERTS values (Figure 9) were found to be lower than corresponding aircraft values by approximately a factor of two. The generally low reflectance results together with the observed relationship between MSS 6 and MSS 7 suggests that the calibration values used are not applicable. Nevertheless the resulting reflectance signatures are useful. The data suggest a 3-channel signature to differentiate the acid-iron waste from other substances in the scene at sufficiently high concentrations. The ratios of reflectance are as follows:

	MSS 4 / MSS 5	MSS 4 / MSS 6
Acid-iron:	2.15	10.7
S.S. Lower Bay:	7.2	21.5
Sewage Sludge:	5.0	18.3

Lake Michigan

Digital processing has been performed on portions of frames 1321-15590 and 1321-15584 (9 June 1973). The data show the coastal transport of the discharge from the highly industrial Burns Waterway Harbor area of Indiana and the coastal entrapment of tributary discharges in the vicinity of Muskegon, Michigan.

NEW TECHNOLOGY

Work has been initiated towards defining the quantitative relationship between suspended solids concentration and ERTS digital integer levels. Much more work remains to be done.

PROGRAM FOR NEXT REPORTING INTERVAL

Final report preparation.

CONCLUSIONS

The investigation demonstrates the potential of ERTS for monitoring large scale events such as ocean dumping of wastes and for water quality monitoring in the Great Lakes. Results indicate that a potential capability exists for determining the near-surface suspended solids distribution through an analysis of ERTS data. This capability could be utilized to estimate suspended solids loading from major tributary sources, delineate major surface circulation features, and determine the spread and movement of major point-sources of pollution.

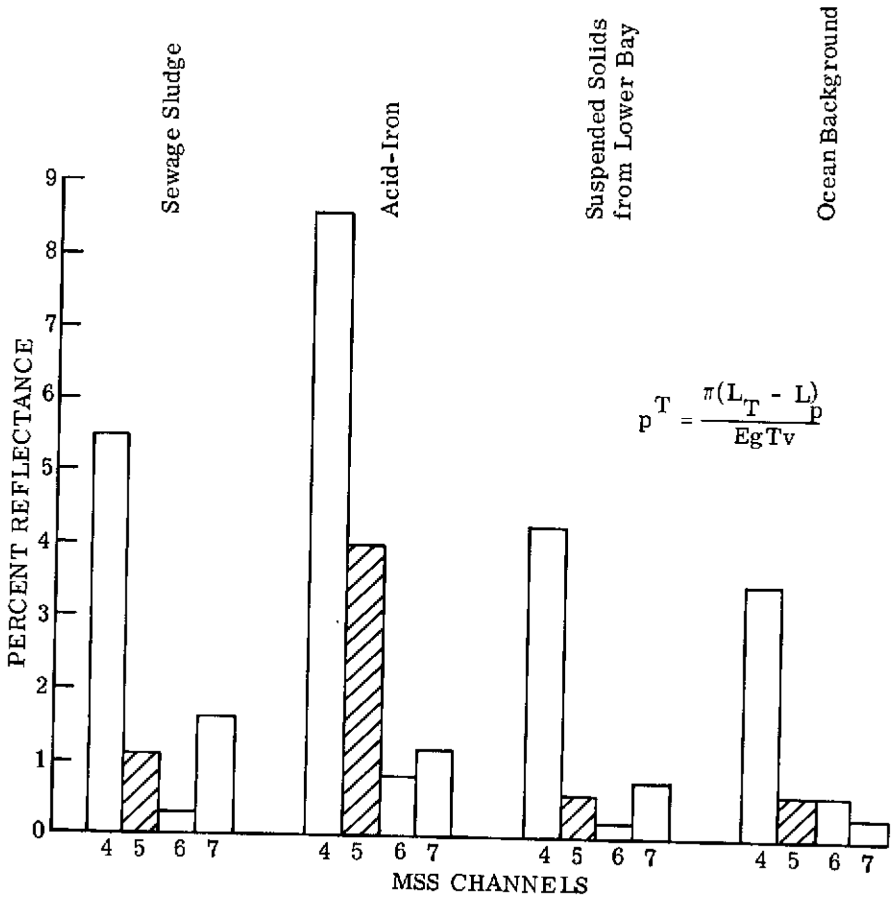


FIGURE 9. ERTS DATA REFLECTANCE SIGNATURES
NEW YORK BIGHT, 16 AUGUST 1972, E1024-15071

RECOMMENDATIONS

A continued effort is recommended to develop an operational capability for measuring suspended solids concentration (surface or near-surface). Concurrent with the above, an effort should be made to develop techniques for delineating areas of high phytoplankton productivity and perhaps estimating phytoplankton concentration levels.

Third Type II Progress Report
R. Horvath, MMC 079
Task IX, Oil Pollution Detection

INTRODUCTION

The overall objective of this investigation is to determine the feasibility of using remote sensing from satellites or spacecraft in order to assist the U. S. Coast Guard in fulfilling its mission in the area of oil pollution detection and monitoring and law enforcement. The hypothesis involved is that the synoptic coverage of vast areas which is possible from spacecraft altitudes will provide an extra dimension and capability to the present Coast Guard program of surface monitoring and remote sensing from aircraft.

Three specific objectives can be defined. The first is to determine the detectability of "small scale" oil slicks associated with illegal dumping of contaminated ballast water, or inadvertant leakage of petroleum cargo, from ships operating in near-shore sea lanes. The most obvious method of "tagging" specific vessels to such occurrences is based upon proximity. However, the synoptic large area coverage capability of spacecraft remote sensing offers the possibility of "tagging" an offender hours after the occurrence by using the vessel's own wake to vector and track between the oil slick and the miles-distant vessel.

The second specific objective of this investigation is to determine the background level of oil pollution due to the presence of heavy industrialization near shipping lanes, and the masking effect of this upon detection of the shipping-associated pollution with which the Coast Guard is primarily concerned. Temporal variations in this background level can be studied by utilizing the repetitive nature of the ERTS coverage.

The third specific objective of this investigation is to demonstrate the utility of spaceborne remote sensing platforms in monitoring the extent and spread of oil slicks resulting from major pollution incidents, such as catastrophic shipping accidents or oil well blow-outs. The large areas extent of such occurrences severely strains the capability of surface and even airborne attempts to define the situation. Timely wide area coverage from a spaceborne sensor could significantly increase the effectiveness with which damage prevention and clean-up operations are deployed.

PROGRESS

Digital data processing of MSS frames 1183-18175 and 1184-18234 has been completed. These frames imaged the 120,000 gal. waste oil spill at Oakland, California in January 1973. Processing has shown that radiance anomalies exist in bands 4, 5, and 6 at the approximate spatial locations of the slick as reported by the U.S. Coast Guard. However, these anomalies are spectrally and quantitatively indistinguishable from natural suspended solids anomalies occurring in the area as a result of tidal cycling. Thus, while we may have detected the oil slick, we certainly cannot state that we have recognized it as such.

There appear to be a number of deleterious effects which contribute to this lack of certainity: 1) the slick was 3 or 4 days old and quite tenuous at the time of ERTS data acquisition; 2) the Inner Harbor is quite narrow (3 to 6 pixels) and thus represents a poor background for detection of a radiometrically subtle anomaly; 3) the dynamic range of the data is compressed into a small number of digital levels as a result of the very conservative MSS gain settings; and 4) raster noise associated with differences in gain and offset between the six detectors producing an MSS channel is of a magnitude comparable to that of the slick anomaly being sought. This latter problem is especially bad in MSS 6, where oil slick detection should otherwise be best. A computer program was implemented in order to correct all channels for this raster noise problem. However, such correction was limited in its utility by the very small dynamic range of the digitized signals.

MSS imagery of the Monongahela River oil spill of June 1973 (frame 1317-15363) and of natural oil seepage in the Santa Barbara Channel (frame 1325-18072) have been received. Interpretation of the Monongahela River images shows no detectable sign of any oil slick. In fact, the river is so narrow (in comparison to ERTS spatial resolution) that even a very intense slick would probably be undetectable due to the relatively low contrast of oil on water. The Santa Barbara frame is uninterpretable due to the presence of heavy fog in the affected area.

We are continuing to keep abreast of plans for a major (500,000 gal.) intentional oil spill to be created in the Atlantic Ocean in March 1974. This is a research-oriented project being conducted by the U.S. Coast Guard and American University with support from other organizations. Assuming continued operational status for the ERTS-1 MSS, coverage of this slick would provide the necessary data to meet the major objectives of this task. The Coast Guard also has plans for creating several smaller (500 gal.) oil spills in late January and early February. An attempt is being made to coordinate these spills with ERTS overflights.

PROGRAM FOR NEXT REPORTING INVERVAL

During the next reporting period, it is hoped that ERTS MSS images will be acquired over intentional spills along Atlantic coastal waters.

NEW TECHNOLOGY	CONCLUSIONS	RECOMMENDATIONS
None	None	None

Third Type II Progress Report
R.K. Vincent, MMC 075
Task X, Mapping Iron Compounds

This task is in the final report writing stage. The report should be completed during the month of February 1974.

The final report will assess the potential for reconaissance mapping and mineral exploration by the processing of ERTS data. Present recognition results for the southern end of the Wind River Range, Wyoming, are being correlated with stratigraphic information area.